ABSTRACT

Title of Document: **Desert Dwelling: A Water Conservative Net-Zero Energy Project**

Matthew Doeller, Master of Architecture, 2015

Directed By: Associate Professor, Ronit Eisenbach, School of Architecture, Planning, and Preservation

The world has begun to recognize that potable, or drinkable, water is a limited commodity that therefore needs to be used conservatively. Growing populations and changing climates are intensifying the need to conserve. At the present, homes built in the United States do not use water or energy efficiently. Reasons for these inefficiencies include abundant cheap energy and water as well as a home building culture that does not design to the natural conditions in local environments. When building culture accepts that the methods and aesthetic of structures must vary based on geography, significant environmental savings can occur. The goal of this project is to establish a variety of water conservative, net-zero energy single-family homes that can be used as prototypes for new development in arid climates throughout the Western United States.

DESERT DWELLING:
A WATER CONSERVATIVE NET-ZERO ENERGY PROJECT

By

Matthew Cole Doeller

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Architecture
2015

Advisory Committee:
Associate Professor Ronit Eisenbach, Chair
Professor Steven W. Hurtt, AIA, Member
Professor Carl Bovill, Member

Preface

I became aware of the water crisis in the Western United States many years ago. As a child, I would visit family in Las Vegas, Nevada and we would spend our days boating and fishing on Lake Mead. As the years went on, it was clear that the water level was declining; leaving a distinct "bathtub" ring around the reservoir. Nine months ago, when I was trying to determine what my thesis was going to be based on, my dad sent me an article about how years of drought have caused the water levels in Lake Mead to reach dangerously low levels. It was at this point that I decided my focus would be on reducing water consumption in the Las Vegas area. As you will learn, the research about water use in that area guided the design to single family homes.

Dedication

This thesis is dedicated to my “Uncle” Sandy. Her love and enthusiasm for life were always an inspiration. I know that she would be first in line to buy a Desert Dwelling if they were to come on the market in Las Vegas.

Acknowledgements

I would like to thank all of the incredible people who have supported me throughout this endeavor. Thank you to my family for their love and encouragement. Thank you to Elizabeth, for putting up with me following the aftermath of long, sleepless nights. I would also like to thank Ronit Eisenbach for your insights and encouragement throughout the process and helping me shape my thesis into a beautiful, functional project that has the potential to have a major environmental impact. Thank you to Professors Hurtt and Bovill for their time, inspiration, and knowledge.

Table of Contents

List of Figures

Chapter 1: Introduction

Water is one of the fundamental necessities of life. With the exception of a few microscopic organisms, plants and animals rely on water to sustain themselves. Humans are no exception. In addition to drinking water, people use water for a variety of other tasks. Most of the products we use and the food we eat require a substantial amount of water to create. The human population now depletes water resources at an alarming rate, faster than it can be replenished through natural processes.

Although the Earth's surface is over 71% water, an extremely limited amount of that water is available for use by humans. Of the water on the planet, 97.5% of it is salt water mostly found in the oceans. The remaining 2.5% is fresh water, but after the ice caps, ground water, and water vapor are factored out, only 0.1% of the Earth's water is available for humans to use.[1] As the global population and developing countries grow there will be an increased strain on natural resources including water. According to the United Nations, "two out of every three people in the world will be facing water shortages by 2025...(and) global

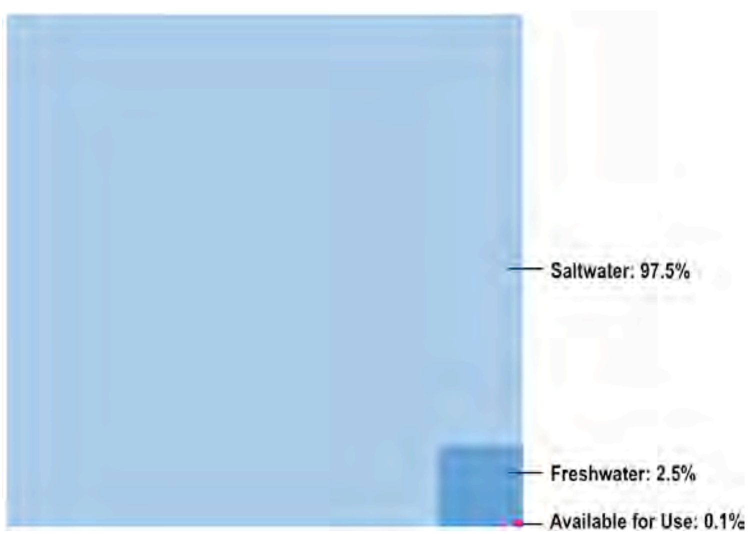


Figure 1: Plenty of Water But Not as Much as You Might Think [Image by Angela Morrelli, Altered by Author]

---

[1] Allan, *Virtual Water*.
[2] Dunn and Felsen, "UrbanLab: Architecture + Urban Design."

conflict will inevitably result...”.[2] It is hard to believe that this prediction is only 11 years away.

The culture of building and use in the United States is contributing to the rapid depletion of natural resources and the overconsumption of energy. Homes, office buildings, and even entire neighborhoods are typically built with a disregard for the climatic, social, and economic environments that surround them. As a result, they are not suited for the environment and waste a considerable amount of water and energy. There are both age-old techniques and modern technologies that can inform the ways architecture can be made more suitable to the surrounding landscape and climatic conditions. By establishing a new prototype, this thesis aims to show that buildings can be responsive to their environmental context in order to conserve water and energy. It is likely that the resulting architectural differences can strengthen the sense of place in addition to the sustainability and viability of living in the desert. Given the high water demands and low water supply of the arid Las Vegas, Nevada region, it shall be used as the context for this thesis.

---

[2] Dunn and Felsen, “UrbanLab: Architecture + Urban Design.”

Chapter 2: Water Use by the Numbers

Water Use in the United States

Withdrawing is a term that means to take away. Withdrawing is the commonly used term to describe the process of taking water from a river, lake, or other source for the purposes of consumption. The United States of America withdraws an exceptional amount of freshwater annually. In 2013, the nation withdrew the third highest total amount of water, 1.27 trillion gallons, following only India and China (231).[3] The United States withdraws an average of 410,000 million gallons per day of freshwater, consuming an inconceivably high amount of water.[4] Over 41% of water consumption is used for thermoelectric power production. Thermoelectric power plants typically withdraw water from rivers in the flow-through style. This means that the water is removed from rivers, used to help cool the equipment, and returned to the river. At 37%, commercial agriculture and other irrigation practices consume the next highest amount of freshwater in the country. This statistic is not isolated to the United States, as 70% of freshwater used globally is for agriculture. As developing countries increase the quantity of meat in their diets

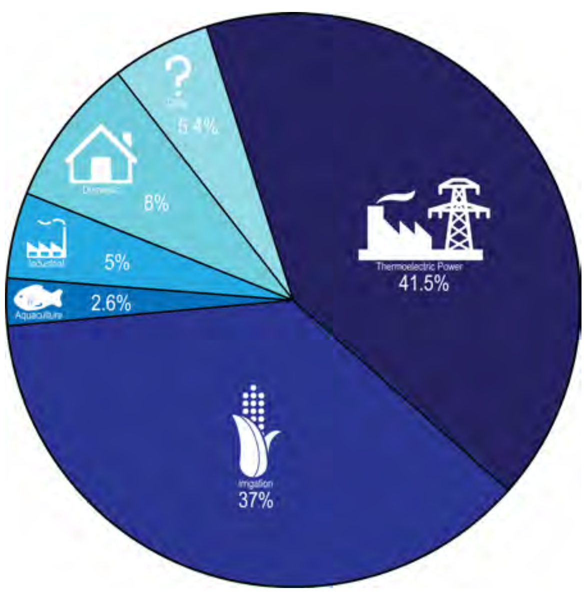


Figure 2: U.S. Freshwater Withdrawals (2005) [Image by Author, Information from EPA]

---

[3] Institute, *The World's Water*.

[4] United States Geological Survey, "Total Water Use in the United States, 2005."

the amount of water used for agriculture is likely to increase.[5] Considering the United States again, the third highest consumption by sector is domestic, meaning the places where people live: single and multi-resident houses, apartments and condominiums.[6] Additional uses in the United States can be found in figure 2. It is also important to note that nationwide, water treatment facilities lose up to 20% of potable water before it reaches the user as a result of failing infrastructure and leaks (110).[7]

Domestic water use in the United States is concentrated in a few areas of the home. According to the United States Environmental Protection Agency (EPA), 30 to 60 percent of urban freshwater is used in the irrigation of lawns. Inside the home, over 40% of water use is in the bathroom, with toilets consuming 26.7% of potable water and showers using another 16.8% annually. Washing clothes uses 21.7%, while faucets in kitchens and bathrooms consume 15.7% annually. Similar to the nationwide infrastructure problems resulting in water loss en route, leaky domestic pipes make up 13.7% of water use annually[8]. More specifically, certain plumbing fixtures and activities use different

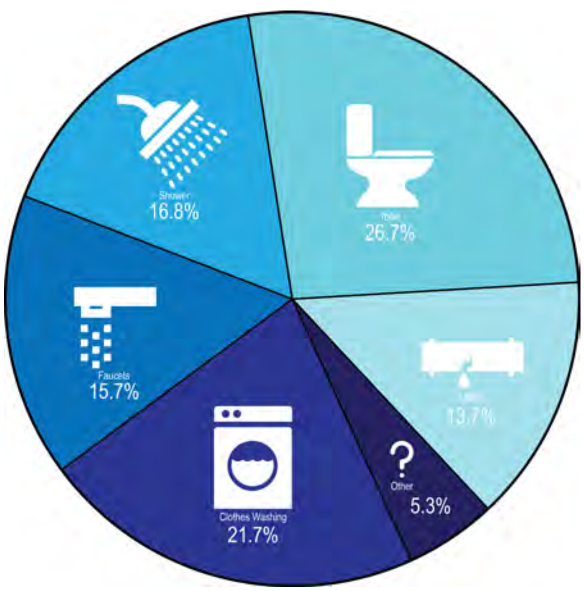


Figure 3: U.S. Indoor Domestic Water Use (2005) [Image by Author, Information from EPA]

[5] Decker, "A Proactive Perspective: Raising a 'Sustainable Water Generation' to Better Care for Water Resources."
[6] United States Environmental Protection Agency, "Water Use Today."
[7] Decker, "A Proactive Perspective: Raising a 'Sustainable Water Generation' to Better Care for Water Resources."
[8] United States Environmental Protection Agency, "Water Use Today."

amounts of water. For example, taking a bath can result in the use of 36 gallons of water per bath. A ten-minute shower using a low-flow showerhead that uses 2 gallons/min can cut that amount down to about 20 gallons. That same ten-minute shower using an older model showerhead can use 4 gallons/min or about 40 gallons total. Depending on the style, toilets use between 1.2 and 3 gallons of water per flush. Turning the water off while brushing teeth can result in using less than 1 gallon of water while leaving the water on can use over 2 gallons each time. It takes an average of 1 gallon of water to wash your hands. Washing dishes by hand uses approximately 2 gallons/min and a dishwasher averages 20 gallons per cycle. Depending on their efficiency, washing machines use anywhere from 25 to 40 gallons per load of laundry.[9] Most homes in the U.S. have a centralized water heater to supply hot water to the entire home. It is estimated that these systems waste an average of 10,000 gallons of water annually because people wait for the water to warm up before getting in the shower or washing the dishes (53).[10] At the household scale, it is clear that the focus areas for water conservation are the landscape and bathrooms. Energy conservation also decreases water use related to the power production of hydroelectric dams and the cooling of thermoelectric power plants.

Water Use in Las Vegas, Nevada

Las Vegas, Nevada is located in the Mojave Desert. Natural sources, including water, are limited. In order to supply Las Vegas's growing population, the Southern Nevada Water Authority (SNWA) receives 90% of its water from Lake Mead, one of the largest reservoirs in the world. It was formed on the Colorado River

[9] United States Green Building Council, "Per Capita Water Use."
[10] Kaufmann and Remick, *Prefab Green*.

following the completion of Hoover Dam, a hydroelectric power plant that borders Nevada and Arizona. At over 1.5 million acres in size, the reservoir is over twice the size of the state of Rhode Island. However, severe drought and other climatic changes have led to a reduction in the flow of the Colorado River, causing the water level in Lake Mead to drop by as much as 2 feet per month (47).[11] According to the SNWA, as part of the Law of the River compact, Nevada is allocated 300,000 acre-feet of water from the Colorado River annually. 1 acre-foot is equivalent to 325,851 gallons of water.

The SNWA withdraws more than the 300,000 acre-feet of water because the allotment is for net consumption. Net consumption, in this context, refers to the amount of water that is taken from Lake Mead and the Colorado River that is not equaled by the amount that is put back into the water body after being treated. The SNWA treats its wastewater and discharges it back into the lake. If the amount being put back into the lake equals the amount being withdrawn then the net consumption would be 0. By reclaiming all of their wastewater, treating it, and discharging it back into the tributaries leading to the Colorado River, the SNWA gains return water credits that allow it to withdraw more water. As a result of these return water credits, the regional water policies do not allow individual property owners to retain any rainwater runoff onsite. However, various water authorities directly reuse a small portion of their wastewater. Boulder City, for example, directly reuses some of its wastewater in sand and gravel operations. The City of Las Vegas supplies reclaimed water to a power plant and several golf course irrigation systems. The City of

[11] Yudelson, *Dry Run: Preventing the Next Urban Water Crisis*.

Henderson uses portions of its reclaimed water to irrigate public parks, schools, and golf courses.[12] Despite reclaiming all of the wastewater, issues of water consumption remain.

> "Las Vegas has among the highest water use per capita in North America, as a result of importing a suburban American lifestyle based on 30 to 50 inches of rain per year into a desert where annual rainfall averages only 4.5 inches. Add swimming pools and golf courses to green lawns and you have water use that far exceeds what nature supplies; only the mammoth nearby Lake Mead allows Las Vegas a reasonably reliable water supply." (47)[13]

However, "Lake Mead...is at its lowest level since construction of the Hoover Dam, and yet Las Vegas continues to use almost twice the amount of water per capita as the rest of the United States" (110).[14] The largest consumer of water use in the Las Vegas area is the single-family home, which consumes 43% of the potable water.[15] Of that water being used by single-family homes, 60% is consumed outside of the home. Traditional lawns and plants, as well as pools are the consumers of this water.

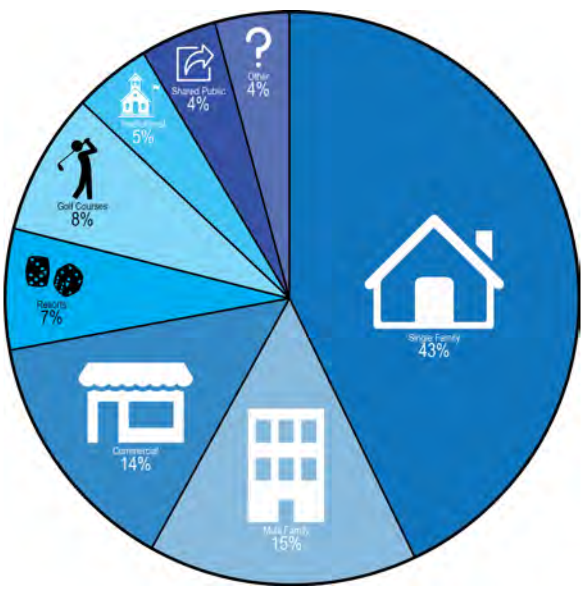


Figure 4: Las Vegas Land Use by Sector (2004) [Image by Author, Information from Western Resource Advocates]

---

[12] Southern Nevada Water Authority, "Water Sources."

[13] Yudelson, *Dry Run: Preventing the Next Urban Water Crisis*.

[14] Decker, "A Proactive Perspective: Raising a 'Sustainable Water Generation' to Better Care for Water Resources."

[15] Hutchins-Cabibi, Miller, and Schwartz, *Water in the Urban Southwest*.

Evaporation from pools results in a large amount of water daily. In fact, a pool that is left uncovered during the summer loses an average of 0.67 gallons of water daily because of evaporation. Simply covering the pool can reduce that amount to about 0.37 gallons daily.[16] Over the course of a year, an uncovered pool would lose almost 245 gallons of water, where as a covered pool would lose 135; a 110 gallons reduction. Multifamily homes are the second highest consumer of potable water with 15% of the total use. Commercial ventures use 14%, golf courses 8%, resorts and hotels consume 7%, institutional buildings use 5%, and other public buildings constitute 4%. Similar divisions of water use are evident in other desert cities. For example, 55% of water use in Albuquerque, New Mexico is consumed by single-family homes and 12% by multifamily. The same pattern is evident in Tucson, Arizona as well; there 55% of water is used by single-family homes and 20% by multifamily.[17]

Water Conservation in Las Vegas, Nevada

The Las Vegas area, and Nevada as a whole, has already taken measures to reduce water use. In 2003 the Southern Nevada Water Authority implemented a drought plan. It is considered one of the most aggressive plans of its kind in the country. The drought plan intends to continuously maximize the amount of water saved and change user habits while minimizing the impacts one the quality of life of citizens and visitors in Las Vegas. One of the major aspects of the plan is stricter regulations regarding lawn size limits and mandated watering schedules. The plan

[16] McCown, *Southern Nevada Inventory of Sustainble Systems*.
[17] Hutchins-Cabibi, Miller, and Schwartz, *Water in the Urban Southwest*.

also established higher water waste fees and water use budgets for golf courses. Perhaps the most successful part of the plan is the Water Smart Landscape rebates. These are rebates that are given to property owners who replace existing grass lawns with xeriscaping. Xeriscaping will be discussed further in chapter four. Thanks to the drought plan and conservation rebates, Southern Nevada was able to reduce its use by 36 billion gallons of water between 2002 and 2011 while increasing the population by 400,000 people.[18] The most limiting aspect of this drought plan is that it only addresses water conservation outside of homes or businesses. In fact, despite the drought plan and conservation rebates, per capita water use in Nevada is expected to remain between 150-200 gallons per day while the population is expected to increase by 114% by the year 2030.[19]

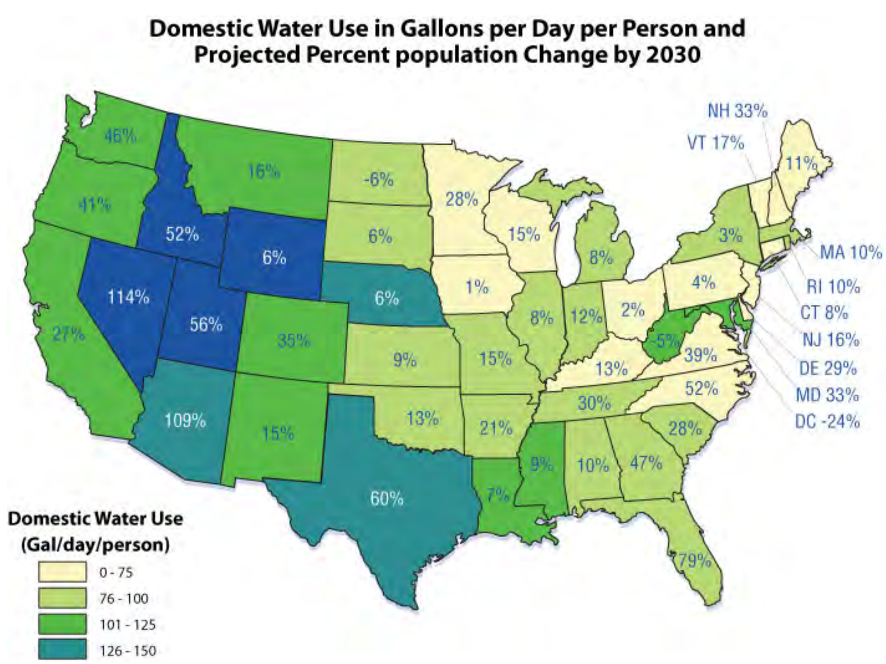


Figure 517: Daily Water use Per Capita and Projected Population Change by 2030 [Image by EPA]

[18] Colorado River Water Users Association, "Nevada."
[19] United States Environmental Protection Agency, "Tomorrow and Beyond."

In an effort to reduce the amount of potable water used within the home, the Southern Nevada Water Authority has developed a Water Smart Certification for new homes. These homes save an average of 75,000 gallons of water annually when compared to a home built in the area a decade ago. There is a strict set of criteria that each home must meet in order to qualify. For instance, front lawns must have water-smart landscaping, trees, flowers, or groundcovers with no grass. Backyards are only allowed to have grass for up to half the total area of the property to a maximum of 1,000 square feet. If a homeowner wants to have a pool, the area of pool is subtracted from their allotment of grass. Water features associated with the pool cannot have water falling more than 2 feet from the surface and ornamental fountains throughout the yard are prohibited. Any irrigation systems must be designed to eliminate runoff. They must also have separate controls to water different plant types. If landscapes require irrigation, drip irrigation is required for planter beds; sprinkler heads can only water grass. There are strict guidelines within the home as well, such as the use of water efficient fixtures throughout. Toilets cannot use more than 1.28 gallons per flush, showerheads no more than 2.5 gallons per minute, and bathroom faucets a maximum of 1.5 gallons per minute. Hot water recirculating systems, that provide a noticeable change in water temperature at or before a half-gallon of water flows from the fixture, are also

Figure 6: Typical New Construction Home with Water Smart Certification [Image by KB Homes]

mandatory in order to qualify as Water Smart.[20] The overall design of Water Smart Certified homes do not vary from those that are not. This thesis aims to identify additional ways to conserve water through various means, including the fixtures and design of the home.

[20] Southern Nevada Water Authority, "Water Smart Home."

Chapter 3: Water Conservation Strategies

Passive Strategies

Some of the most effective methods for conserving water are those that are the most simple to execute. Among these methods is xeriscaping, which is widely used in the Las Vegas area. Conventional lawns can use up to 17 gallons of water per square foot annually where as a xeriscape may require less than 3 gallons per square foot annually.

> "The core objective of xeriscaping is water conservation through the creation of water-efficient landscapes. A properly designed outdoor xeriscape not only reduces water usage by 20 to 50 percent, but can also reduce chemical usage, requires little maintenance, and can be uniquely aesthetic (232)."[21]

These reductions in water use result from several things. The overall design concept is to minimize grass lawns in exchange for plants that are native to the region. Native plants are accustomed to the climate in which they live, meaning that plants native to the desert can go for long periods of time in intense sunlight with minimal water. Examples of these plants would be the Joshua Tree, Desert Marigold, Utah Agave, and Mexican Evening Primrose.[22] As figure 7 shows, xeriscaping can be an aesthetically pleasing alternative to conventional turf lawns while requiring significantly less water.

---

[21] Friedman, *Innovative Houses: Concepts for Sustainable Living*.

[22] DesertSol, "Public Exhibit Signage."

Figure 7: Before and After Xeriscaping of a Utah Residence [Image by Xeriscape Design L.C.]

The cost of water throughout the country varies greatly. The major factors that contribute to water costs are proximity and infrastructure costs. For instance, the northeastern states around the Great Lakes have some of the lowest water bills in the country. This is largely because their proximity to the Great Lakes requires less piping and infrastructure and also because the lakes are an immense source of freshwater. One would suspect that arid parts of the American Southwest would have the highest rates given their climate and the scarcity of water. However, since the federal government paid for or subsidized most of the infrastructure construction, it

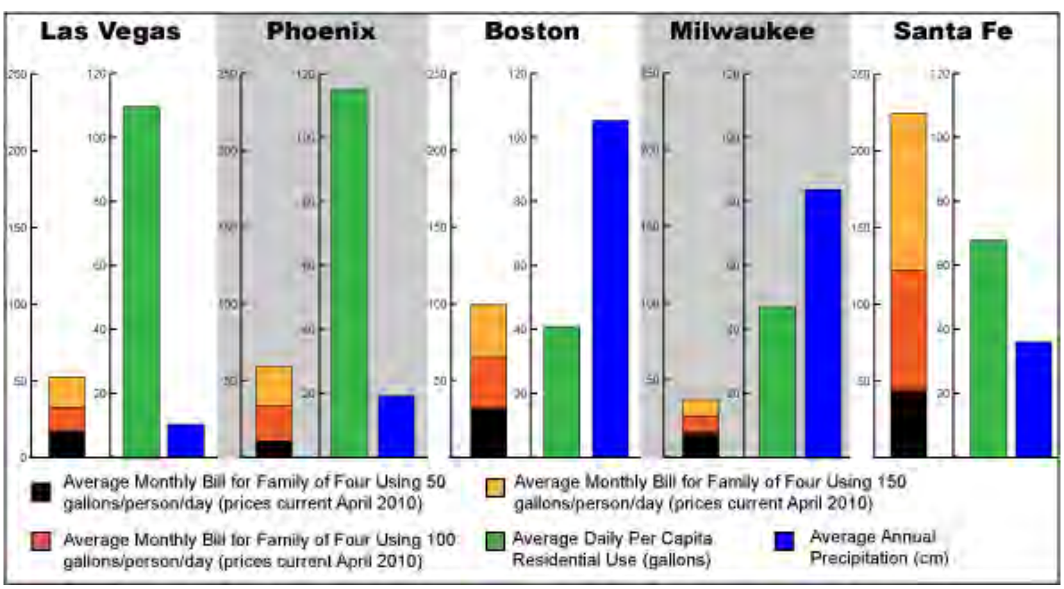


Figure 8: Water Use Comparison of 5 U.S. Cities [Image by Trevor Seela]

turns out that many desert cities, such as Las Vegas, pay less for water because the municipalities do not have as high a burden associated with the initial cost of infrastructure.[23] This is evident in figure 8. Although it would not be a permanent solution, increasing the cost of water would likely cut water use as the population began to cut back on their water use to reduce their monthly water bill. The Las Vegas Valley Water District (LVVWD), one of the SNWA member agencies, has been looking closely at the cost of water to curb usage. As evident in figure 9, the pricing system has changed in recent years causing consumers to reach higher pricing tiers at a faster rate. Each pricing tier is based on gallons used. This incentivizes customers to cut their water use. Although prices could be higher, water agencies choose to keep them where they are so that the profit margins remain steady.[24]

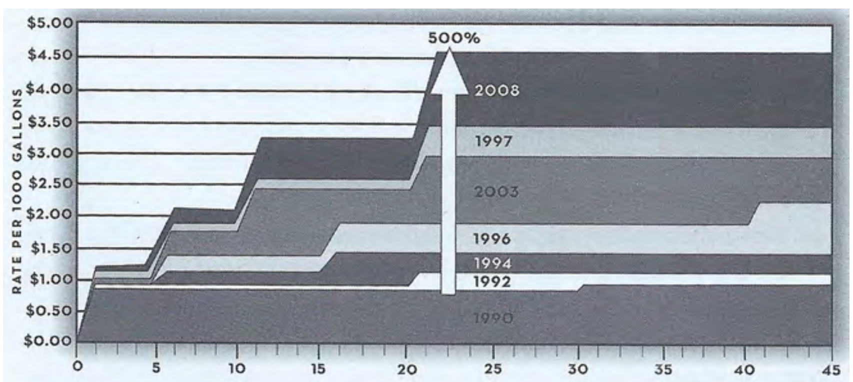


Figure 9: Water Pricing Tiers of the Las Vegas Valley Water District [Image by LVVWD]

Public education can go a long way in helping to change cultural habits. There are several programs and demonstration sites that aid in this cultural change within the Las Vegas area. One of these programs addresses the hotel industry and the tourists that may not be aware of Southern Nevada's water scarcity. The program informs guests upon check-in that in an effort to conserve water bed linens will only be changed every 3 days, unless otherwise requested. This program is fairly common

[23] Walton, "The Price of Water: A Comparison of Water Rates, Usage in 30 U.S. Cities."
[24] Yudelson, *Dry Run: Preventing the Next Urban Water Crisis*.

throughout the rest of the country as well. Demonstration programs are also a great resource to educate the public. Many people are visual learners and it helps them to see the solutions as opposed to visualizing them based on written information. One of the best demonstration projects in the Las Vegas area is the Las Vegas Springs Preserve. The Springs Preserve is a 180-acre natural wetlands located not too far from the heart of downtown Las Vegas. It is designed to be a model for sustainable desert living. The Springs Preserve offers demonstration gardens that show various forms of water conservation, including xeriscaping. Along with the gardens, the University of Nevada Las Vegas' 2013 Solar Decathlon house (DesertSOL) is permanently on display at the preserve as a demonstration for visitors of what a present day desert home could look like. DesertSOL will be discussed further in chapter 6. All of the other buildings at the Springs Preserve are certified LEED Platinum.[25]

<u>*Active Strategies*</u>

As the global consciousness continues to recognize that water is a precious resource, technological advances are emerging to help reduce, reuse, and even "create" water. One of the most common methods of conserving water in the home is using low-flow fixtures and high efficiency appliances. For instance, changing toilets to dual flush or high efficiency can save up to 4,000 gallons per year. Switching to low-flow showerheads can save 7,800 gallons per year for each 5-minute shower. Installing sink aerators, devices that introduce air into the water flow at the faucet, can reduce each sink's water use by 1,700 gallons per year. Having an Energy Star

[25] Springs Preserve, "The Springs Preserve."

certified dishwasher can save 1,250 gallons per year and an Energy Star certified washing machine can save 11,000 gallons annually.[26]

People have come to realize that not all wastewater is the same. Based on the content of the wastewater, it can be reused in different ways before being returned to the municipality via the sewer system. For instance, greywater is a term used to describe wastewater that does not contain human waste. Greywater includes wastewater from showers, bathroom sinks, and laundry machines. With minimal filtering, greywater can then be used to flush toilets or irrigate landscapes. A system that takes advantage of this is the Sloan AQUS® Water Reuse System. This relatively simple system takes the wastewater from bathroom sinks, filters and disinfects it, and discharges it into the toilet tank.[27] Another technological tool that addresses greywater is the EcoDrain. This system, which does not have any moving parts, transfers the heat from soiled shower water to new, cold water before it gets to the shower. By doing this, the system reduces the demand for hot water and therefore also saves the energy associated with heating water. The EcoDrain system can save up to $250 annually, in addition to the water and energy conservation.[28] Monitoring systems can also help make residents aware of their water consumption and help indicate the problem areas. The Echo Water system by Belkin monitors the water use of each fixture. When attached to the

Figure 10: Sloan AQUS [Image by Sloan Valve Company]

[26] Yudelson, *Dry Run: Preventing the Next Urban Water Crisis*.
[27] Sloan, "New Sloan AQUS® Water Reuse System Model."
[28] EcoDrain, "Take a Smarter Shower."

cold water supply line of the kitchen sink, the Echo Water system uses the vibrations in the piping to determine the amount of water use in each fixture.[29] Monitoring and knowing how much water is being consumed is the first step in determining conservation strategies.

In many cases, collected rainwater can be used in a similar fashion to greywater. It can be collected in cisterns or barrels and then used to flush toilets and irrigate the landscape. The issue with harvesting rainwater in the Las Vegas area is that the annual rainfall is only 4.5" annually. Blackwater is the term used to describe wastewater that contains biological wastes. Toilet water is considered blackwater. Although there are technologies that can treat blackwater on site, they require a great deal of space and are costly. They would not be viable for use in a single-family housing prototype, however more consideration to the viability of this option could be given if relatively large multifamily prototype is developed. One way to eliminate blackwater altogether is to install composting toilets. Without the use of water, these toilets collect human waste in a chamber beneath the toilet where it is broken down over time. The composted waste can then be used to fertilize vegetation. It is uncommon to find a composting toilet in a home; they are typically located in places where water is scarce or remote locations where plumbing would be too costly. For example, they are common throughout the national parks facilities. The Phillip Merrill Environmental Center on the Chesapeake

Figure 11: Signage for a Composting Toilet [Image by Author]

[29] International, "Echo Water."

Bay shows its commitment to the environment by having composting toilets throughout its office and educational spaces.

A French company, Eole Water, has developed methods to condense water vapor into drinkable water. These systems operate using a humidity condenser and heat exchanger to extract water vapor from the air. The company has a model where the condensing unit is located inside of a wind turbine and another where the condenser is powered by solar panels and the excess energy is available for use.

Figure 12: Eole Water's Wind Turbine and Water Generator [Image by Eole Water]

There are several drawbacks to these systems. The first is that the humidity in desert environments is relatively low. This brings the output of potable water from 375 gallons per day down to about 100 gallons per day. Besides only "creating" approximately a quarter of the water, the wind turbine system currently costs $790,000 making it impractical as a sustainable prototype for an individual home.[30]

As noted earlier, centralized hot water heaters are common in most homes. The issue with heating water at one source, and distributing it to the faucets as needed, is that there can be a long delay before the water coming out of the faucet warms up. It is estimated that these systems waste an average of 10,000 gallons of water annually because people wait for the water to warm up before getting into the

[30] Eole Water, "Clean Technology for Clean Water."

shower or washing their dishes.[31] There are alternative systems, known as on-demand or tankless water heaters, which can significantly reduce the amount of water that is wasted waiting for the temperature to become comfortable. Tankless water heaters rely on electric or gas to rapidly increase the water temperature. Locating a small tankless system by each fixture can increase the water savings further. On-demand water heaters also conserve energy because they do not require water to be constantly heated while waiting to be used.[32]

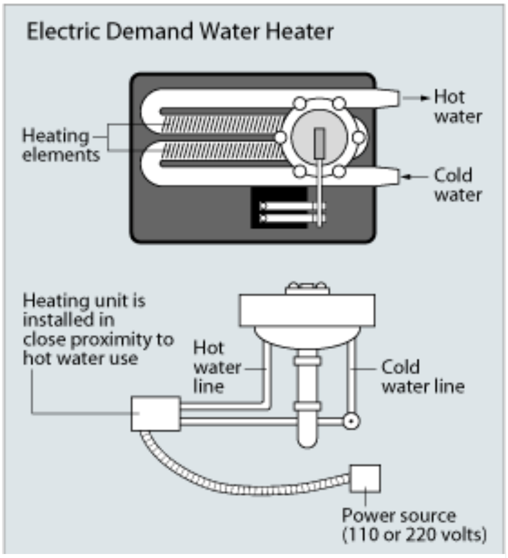


Figure 13: Diagram of a Tankless Water Heater [Image by DOE]

[31] Kaufmann and Remick, *Prefab Green*.
[32] United States Department of Energy, "Tankless of Demand-Type Water Heaters."

Chapter 4: Statistics of Energy Use

The Water-Energy Nexus

A nexus is a connection or series of connections that link two or more things together. There is a growing understanding that the production of energy and the use of water are linked in a way that makes them dependent upon each other. As the National Conference of State Legislatures stated,

> "Water and energy are linked at both the supply side (electric generation and water/wastewater facilities) and the end-use side (residential, commercial, industrial, and agriculture sectors). In order to sustain energy production and a dependable water supply, the U.S. must gain a detailed understanding of the interdependence of water and energy systems and balance the needs of all users."[33]

The process of energy creation requires water in the areas of thermoelectric and hydroelectric power production, fuel production, and mineral mining. At the same time, energy is required to pump, treat, and distribute water. Concerns about climate change are helping to bring increased recognition to the interdependency of these systems. This is because "a warmer climate will bring about greater evaporation rates from rivers, canals, and reservoirs, while simultaneously increasing demand by crops and city landscaping."[34] These climatic changes will increase awareness of the link between energy and water.

---

[33] Atkinson, "The Missing Link."
[34] Kenney and Wilkinson, *The Water-Energy Nexus in the American West*.

It is becoming clear that utility companies for both electricity and water supply would mutually benefit if they worked together to educate the public about the issue. Currently, there is a lack of communication between these organizations and this results in the wasting of energy and water. For instance, many electric companies provide rebates for appliances that use less energy but those same appliances may use more water. Conversely, many water municipalities offer rebates for customers who buy water efficient appliances. However, it is common for these appliances to require more energy.[35] It seems logical that local municipalities should work together with manufacturers to identify appliances that conserve both water and energy.

Energy Use in the United States

In 2010, the United States was the second highest consumer of energy per capita following only Canada.[36] As figure 14 shows, in 2012, 40% of the energy consumed in the United States goes to the production of electricity. Transportation needs use 28%, Industrial purposes consume another 22%, and residential and commercial needs make up the remaining 10% of total energy consumption. A missed opportunity is that only 9% of the energy consumed is generated from renewable sources like solar and wind. When taking a closer look at the built environments' contributions to energy use within the United States, the statistics show that significant improvements can be made. According to the Energy Information Administration (EIA) residential and commercial buildings consume 41% of the energy used by all buildings. They also use 74% of the nation's electricity. In fact, the level of energy use and the resulting CO_2 emissions associated

[35] Atkinson, "The Missing Link."
[36] "Per Capita Energy Consumption - Energy Realities - A Visual Guide to Global Energy Needs."

with buildings are almost as high as that of the transportation and industrial levels combined. Yet a 2007 national survey of 1,000 households found that 75% of them said that they believed their homes had no adverse environmental impacts.[37] It is time to increase awareness about the importance of conserving energy and to design buildings that are more energy conscious. Without proper education, the higher initial costs associated with sustainable buildings make many consumers avoid them. On average, sustainable buildings cost between $3 and $9 more per square foot than their standard counterparts.[38]

Energy Use in Las Vegas, Nevada

Nevada is ranked 41st in total energy consumption per capita in the United States. The state is also ranked 45th in cost per person for energy, at $3,624 annually.

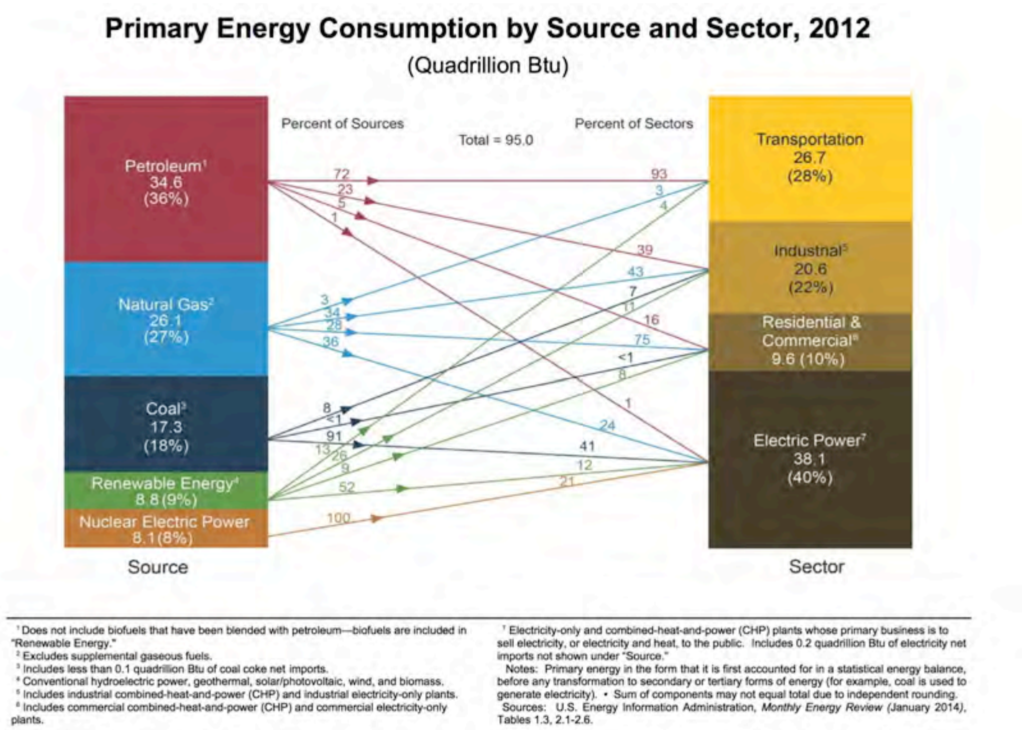


Figure 14: U.S. Energy Consumption by Source and Sector (2012) [Image by EIA]

37 Kats, *Greening Our Built World: Costs, Benefits, and Strategies.*
38 Ibid.

The major issue with energy consumption in Nevada is the source of energy. In fact, 90% of the energy consumed in the state is produced outside of it. A majority of the petroleum products used to create energy in Las Vegas come from California pipelines. However, in 2012 a 400-mile pipeline opened that lets petroleum products from refineries near Salt Lake City, Utah reach Las Vegas. Relying on other states for the raw materials to produce energy is not a sustainable model because of the energy and costs associated with transporting them long distances.[39]

Energy consumption by sector in Nevada is atypical of most states. As a result of the high levels of tourism, the transportation sector consumes a little less than a third of the state's energy demands. Industrial functions consume approximately 25% of the energy and the commercial sector another 18%. The residential sector constitutes about 24% of the energy demands for the state.[40] Although homes are not the leading user of energy in Nevada, minimizing their energy consumption will create a more sustainable environment for all and improve the long-term sustainability of Las Vegas, a city in the desert.

Figure 15: Nevada's Energy Use by Sector (2012) [Image by Author, Information by EIA]

Nevada is continuously increasing the amount of energy that it produces. In 2013, the state generated 68% of its electricity needs by natural gas. Another 9.8% came from utility-scale geothermal and solar energy production. Utility-scale

---

[39] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis."

[40] Ibid.

production refers to a power plant of any kind that generates enough electricity to contribute to the grid. Nevada is ranked second and third in the production of geothermal and solar energy, respectively. This shows that the state is headed in the right direction, as the use of renewable energy sources is steadily increasing. In fact, Nevada has set standards that require 25% of electricity sales to come from renewable sources by 2025. These sources typically require substantially less water to operate. As of 2013, the state is ahead of its goal, having generated 18% of the net electricity from renewable sources such as geothermal, solar, wind, and hydroelectric.[41]

Hoover Dam is one of the largest hydroelectric dams in the country. It is capable of producing 4 billion kWh of electricity annually but as the drought continues, production has had to be reduced. In 2009, it decreased to 3.7 billion kWh and it has decreased further since then.[42] To put that in perspective, 1 kWh would be approximately equivalent to warming up 16 meals in a microwave oven, assuming

Figure 16: Water Levels of Lake Mead Behind Hoover Dam [Images by Paul Mulroy and the Associated Press, combined by author]

that each took 5 minutes. The decrease in production is the result of limited operating hours. The dam has been forced to operate only during peak hours or risk withdrawing water too quickly from Lake Mead. Once the water level is too low, it

---

[41] Ibid.

[42] Kuckro, "ELECTRICITY: Receding Lake Mead Poses Challenges to Hoover Dam's Power Output

will not have enough pressure to spin the turbines that generate electricity. With this in mind, Hoover Dam has invested in major upgrades to the facility that include wide head turbines that are more efficient at all water levels.[43] It is recognized that this does not solve the water crisis in the region and is only a temporary solution to the production of inexpensive, zero carbon emitting hydroelectric power production. It also highlights the concept of the water-energy nexus; as increased withdrawals of water and an ongoing drought are resulting in water levels that are reaching the point where power production cannot occur.

The water-energy nexus in the Las Vegas area is also evident in how the Southern Nevada Water Authority takes and replenishes water from Lake Mead. In order to store water, Hoover Dam and the corresponding Lake Mead reservoir were built at a low point in the valley. Although this is good for collecting and storing water, it makes the process of distributing water more energy intensive. For instance, the SNWA's second water intake pipe is located at 1,000 feet above sea level. The pumping station is 290 feet higher in elevation. The City of Las Vegas is 1,000 feet higher still. Other cities that the SNWA supplies are even higher. In all, the authority must pump water almost 2,300 feet uphill to supply Las Vegas. A common estimate for the cost associated with this is that it takes 1 kWh of energy to raise 1 acre-foot of water 1 foot. This means that the SNWA uses 300,000 kWh of electricity annually to simply pump the water to consumers. In fact, pumping water contributes to 90% of the SNWA's energy bill. The remaining 10% is used to actually treat the water.[44] Returning water to Lake Mead for withdrawal credits also uses a considerable amount

---

[43] Ibid.
[44] McCown, *Southern Nevada Inventory of Sustainble Systems*.

of energy. In order to make the water suitable for return to the reservoir, it is treated to advanced tertiary standards. At this level of treatment, it could be re-distributed directly to consumers at the added cost to pump it there. However, since it is returned to the reservoir and then withdrawn again by the pumping station, more energy is used than is necessary.

Chapter 5: Energy Conservation Strategies

Passive Strategies

Without the assistance of mechanical systems and technological advances, there are several methods for conserving energy that can be implemented in the initial design of a home. The first strategy is to orient the home to take the maximum advantage of the lighting and heating opportunities of the sun. For this to be done, the home should be longer from east to west than it is from north to south. In fact, the United States Green Building Council (USGBC) recommends that the longer, east-west axis be a minimum of 1.5 times longer than the north-south axis. Furthermore, the longer axis should not be more than 15 degrees off of the geographical east-west axis.[45] The goal of solar orientation is to maximize natural daylight year around and gain heat only when desired. Roof overhangs, louvers, and deciduous trees are commonly used to block direct sunlight in the summer months, when it would overheat the home. A section depicting this is shown in figure 17.

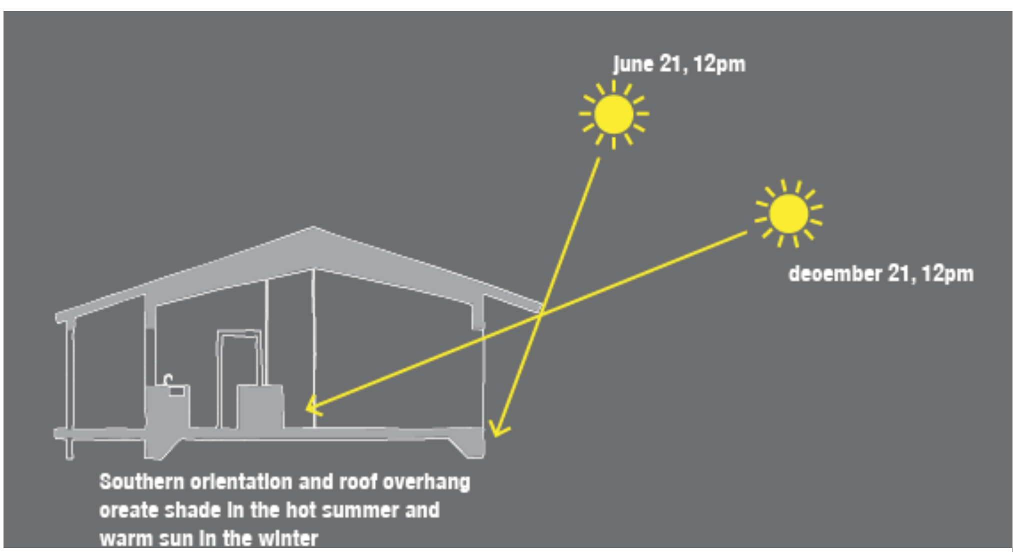


Figure 17: Diagram Showing Passive Solar Orientation [Image by Author for NASHI]

[45] United States Green Building Council, "Solar Orientation."

Thermal mass is another method for conserving energy. It reduces the heating and cooling loads of the building.

> "A thermal mass is a material with the capacity to absorb and store thermal energy and later release significant amounts of heat. It typically includes materials such as concrete, masonry, and earth. Water is also a widely available thermal storage material. Buildings constructed of high thermal mass have a distinctive thermal advantage because they absorb energy slowly and hold it for longer periods of time than do less massive materials, which allow energy to be stored and moderates indoor temperature fluctuations (temperature swings)." [46]

Moderating indoor temperature fluctuations is vital for desert buildings where daytime highs and nightly lows vary tremendously.

Taking advantage of natural breezes can help reduce a homes dependency on mechanical systems for cooling. Proper design of operable windows and doors will promote cooling breezes through the home. Movement of air through the home is achieved through the use of a couple of physical characteristics of air: pressure and temperature. Variations in atmospheric air pressure are one of the leading factors that contribute to wind. Air moves from areas of high pressure to those of low pressure, creating wind. The orientation of openings and walls in the home can create areas of high and low air pressure that promote its movement through the house.[47] Temperature variations also promote air movement. It is well known that warm air rises. Taking advantage of this by incorporating openings at high points of the home

[46] Wujek, *Mechanical and Electrical Systems in Architecture, Engineering, and Construction*.
[47] Koch-Nielsen, *Stay Cool*.

will help to expel warm air from the home which will draw cool air in from lower points.

Active Strategies

Technological advances have led the way for the development of systems that help to conserve energy, as well as creating it in some cases. One of the most well known of these technologies is photovoltaic (PV) panels, also known as solar panels. A PV system collects solar energy and converts it to electricity. There are 3 basic components to a PV system. The first is the array of solar cells that convert sunlight into direct current (DC) electricity. The next component is an inverter, which converts the DC electricity into AC current, which is the electricity type that powers homes. Excess electricity can either be stored in batteries or provided to the local utility grid, assuming the home is connected to it.[48] A drawback to PV systems is their high initial cost. This has been on the decline, but remains high.

Figure 18: PV System on the Roof of WaterShed [Photographer Unknown]

> "Prices for PV have dropped by a third since early 2008, but generally remain substantially higher than grid electricity on a dollars-per-kilowatt basis. However, PV typically reduces grid power use during peak hours, making PV more cost-effective." [49]

[48] Wujek, *Mechanical and Electrical Systems in Architecture, Engineering, and Construction*.
[49] Kats, *Greening Our Built World: Costs, Benefits, and Strategies*.

Costs also vary depending on the type of PV panel that is used. There are several different types, with efficiency and costs being the major differences.

Solar thermal collectors are a great way to conserve energy. Traditional hot water heaters waste a considerable amount of energy reheating water in anticipation of use. Figure 19 shows how flat plate collectors work. These systems pump cold water through narrow tubes located in a panel outside the home.

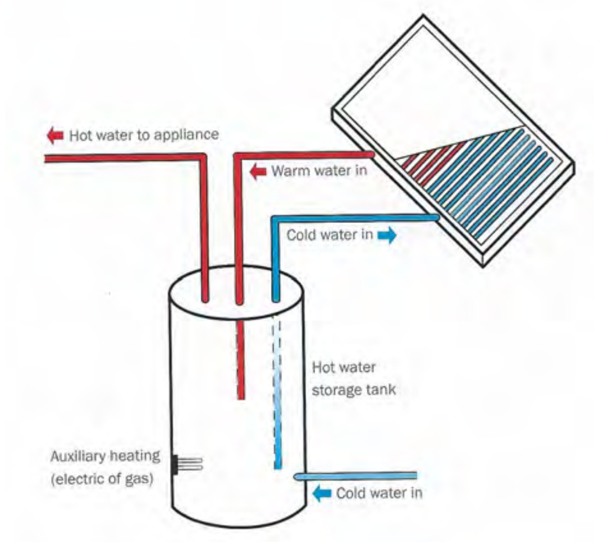


Figure 19: Components of a Water-Heating Solar-Based System [Image by Avi Friedman]

Sunlight heats the water up to 54 degrees greater than the temperature it started at. The heated water is then transferred to a storage tank for distribution inside the home. Although the flat plate collectors can be up to 85% efficient, evacuated tube collectors can be even more efficient. These systems rely on a series of small tubes that have antifreeze in them. When sunlight hits the tubes, the antifreeze turns into steam and rises in the glass tube. After transferring its heat to an adjacent water

Figure 20: Evacuated Tubes Used on WaterShed [Image by Jill Fehrenbacher for Inhabitat]

line, the antifreeze condenses back into a liquid and the process begins again.[50]

The sun's energy can also be used to heat the air within the home. These systems typically manifest themselves as exterior cladding systems. For example, perforated cladding systems consist of a dark metal panel with thousands of small holes in it. With the help of a fan, air is drawn into the holes, where it is heated as a result of the sun warming the dark panel. The heated air is then drawn into the home and distributed as necessary via a conventional duct system.

Geothermal heating systems take advantage of the earth's constant temperature. A geothermal heat pump is "an electrically powered heat pump system that consists of pipes buried in the…ground near a building."[51] There are three main components to a geothermal heating system. The first part is the ground loop, which is a series of fluid-filled plastic pipes that are buried in the ground. After the earth warms the fluid, a heat pump removes the heat from the fluid and transfers it to the house. Conventional air ducts then distribute the heated air. When cooling is needed, the heat pump draws heat from the building and expels it into the ground.[52]

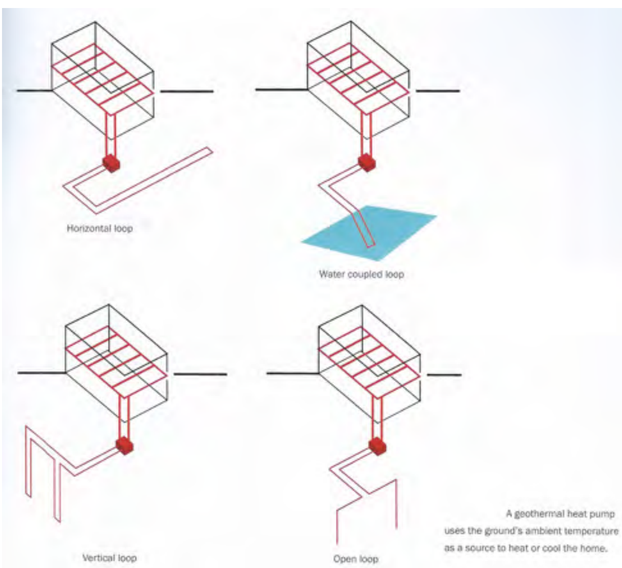


Figure 21: Diagram of the Various Types of Geothermal Systems [Image by Avi Friedman]

[50] Friedman, *Innovative Houses: Concepts for Sustainable Living*.
[51] Wujek, *Mechanical and Electrical Systems in Architecture, Engineering, and Construction*.
[52] Ibid.

Harnessing the power of the wind is another strategy to reduce reliance on energy created with fossil fuels. Similar to the way the turbines at Hoover Dam work with water, wind turbines use the wind to turn large blades. These blades then spin a central shaft, which connects to the generator creating electricity. Although very large commercial scale turbines exist, small-scale turbines that produce about 100 kilowatts are available for residential applications. Like PV systems, excess electricity generated by wind turbines can be stored in a battery bank or returned to the utility grid. Wind turbines are frequently used in conjunction with PV systems in a hybrid system.[53]

[53] United States Department of Energy, "How Do Wind Turbines Work."

Chapter 6: Considerations for Designing Vernacular Desert Architecture

What is Vernacular

> "In the past, buildings were constructed using passive measures (to heat and cool), quite obviously due to the lack of any energy supply or resources. In industrialized countries, active measures gained predominant use during the post World War II construction boom, as an easy and quick means of satisfying comfort concerns in buildings. In this process architecture lost its connection to 'place.' It was now possible to create built environments that were totally controlled and divorced from their surroundings. This may consequently have resulted in the lack of attention paid to the real costs associated with this form of progress." [54]

This quote points to the loss of a vernacular strategy for adapting architecture to its location and with it, an authentic style connected to place. It shows an understanding that buildings should be designed to respond to the climate and context in which they are located. Technological advances and inventions in building construction, temperature control, lighting, and energy meant that it became easier to condition air mechanically to meet the needs of the occupants. Heating, cooling, humidifying, and circulating can all be done using mechanical systems where there is a lack of concern for waste: how much heat and air are gained or lost through the walls and windows. This has led to architecture that looks the same in dry, arid environments as it does in humid, cool ones. For instance, the Water Smart Certified Home from figure 6 back

[54] Koch-Nielsen, *Stay Cool*.

in chapter 2 is being built throughout the Las Vegas area. If it had aluminum siding and an asphalt shingle roof, instead of stucco and clay tile, it could be found in suburbs throughout the Northeastern United States. A return to principles set forth in desert vernacular architecture will help ensure a more sustainable way of life. This will be discussed further in a later chapter.

The Climate and its Considerations

Las Vegas, Nevada is the largest city in the state. It is located in a southern Nevada valley that is surrounded almost entirely by mountains that tower as much as 10,000 feet higher than its elevation. Average temperatures throughout the year are around 83 degrees Fahrenheit. The end of July and beginning of August are the warmest months, with daytime highs reaching over 100 degrees and lows staying in the 80s. Las Vegas is a cooling dominated environment averaging 3,568 cooling degree-days annually. A cooling degree-day is a method used to determine how much energy will be used to cool the home on a given day. It is calculated by subtracting 65 degrees from the average temperature for the day.[55] Conditioning air to comfortable levels indoors requires large amounts of energy. In fact, homes in dry, arid climates such as Nevada spend 70% to 80% of their energy conditioning air throughout the lifetime of the home.[56]

The amount of precipitation is also something to consider when building in the desert. The Mojave Desert is what is known as a rain shadow desert. A rain shadow desert is an area that becomes a desert because adjacent mountains prevent

[55] Stachelski, Gorelow, and Skrbac, *The Climate of Las Vegas, Nevada*.
[56] Koch-Nielsen, *Stay Cool*.

moisture filled air from reaching the region.[57] As moist air increases in elevation on the western side of the mountains it condenses into rain or snow that precipitates out of the clouds before crossing the summit of the mountains. For this reason, Las Vegas averages 4.5 inches of rain annually. In addition to the yearly amount of rainfall, it is important to note that each rain event yields very little water. In fact, there are only 25 instances since 1937 when more than 1 inch of rain accumulated within a 24-hour period.[58] Designing to collect or get the most use from the small amounts of rainfall will help to make the home less dependent on the municipal water supply.

Solar radiation is a large contributor to the heat gain of homes in the desert. There are three types of solar radiation that affect buildings. The first is direct radiation. This occurs when solar rays hit a building's surfaces without interference. The second method is diffused radiation, where solar rays hit a building after passing through clouds. The final component is known as reflected radiation, which occurs when solar rays strike the building after bouncing off of other surfaces including the ground and adjacent buildings.[59] Considering solar radiation in the design of the home has effects on the location and mass of walls and roofs as well as the orientation of the entire home and window placement. This is especially important in the Las Vegas area, which averages 210 days of sunny, clear skies annually. Another 82 days are only partially cloudy.[60]

---

[57] National Geographic, "Rain Shadow."
[58] Stachelski, Gorelow, and Skrbac, *The Climate of Las Vegas, Nevada*.
[59] Ibid.
[60] Ibid.

Wind, air temperature, and humidity are other climatic factors that need to be considered when designing a home in the desert. The most important aspect of the wind is the velocity (speed and direction) and the frequency that it occurs. Knowing these can help to determine the best orientation for the home and windows to allow for natural ventilation. Circulating air around and through the home aids in the cooling process without the need for mechanical systems.[61] In fact, air movement of 1 mph can have a cooling effect of 3 degrees Fahrenheit.[62] Air temperatures play a roll in occupant comfort and air circulation. In Las Vegas, high diurnal variations need to be accounted for. Diurnal variation is the difference between the high and low temperatures of the day. There is a design opportunity to passively cool the home using cool nighttime breezes. Humidity also plays a role in personal comfort. Humidity is the measure of water vapor in the air. As humidity increases, it restricts the body's ability to cool itself through perspiration. Furthermore, as air temperature increase, the air's capacity to retain water vapor increases as well. This is why desert environments are hot and dry.

The Built Environment

Vernacular architecture can help to establish a sense of place. For homes in the desert, there are certain design principles that should be established. The first is that buildings should be compact in size, and programed so that the activities are focused inward. This will reduce the amount of surface area that is exposed to solar radiation. With solar radiation in mind, large surfaces on the southern side of the home will receive solar gains throughout the day, and the east and west walls receive

---

[61] Koch-Nielsen, *Stay Cool*.
[62] Hurtt, Thesis Meetings.

high intensities of solar radiation in the morning and afternoon, respectively. To take advantage of shading opportunities individual buildings should be clustered closely together for mutual shading of exposed surfaces. Projecting rooflines, verandas, trees, perimeter walls, and other shading devices can also help to establish comfortable living areas outside of the home. Windows should be designed to maximize the circulation of dust free air to aid in cooling. Distribution of air will improve if window openings are oriented at 45 degrees to the prevailing wind direction.[63] Using these design principles during the initial design phases will help return the architecture to design that is appropriate to the desert climate and maximizes the opportunities the desert offers.

The Build Envelope and its Components

The building envelope of a desert home that aims to be energy efficient has to achieve several important goals. The first is to reduce heat gain during the day. The second goal is to act mediate the high diurnal temperature variations from day to night.

Proper wall design is vital to the building envelope successfully achieving these goals. Similar to the overall design of the home, there are strategies to maximize the envelope's performance. The first strategy is to minimize the amount of wall that faces east and west. East facing walls receive high amounts of solar radiation in the morning. This may cause them to release stored heat too early in the day. Increasing the thermal mass of the eastern walls can minimize this issue. Given the high diurnal temperatures, all exterior walls should have high amounts of thermal

[63] Koch-Nielsen, *Stay Cool*.

mass to mitigate the temperature swings from daytime highs to nighttime lows. By storing heat during the day, the walls prevent the house from overheating. At night, when nighttime temperatures are low, the walls slowly radiate heat toward the interior, making the room comfortable. Including operable windows will also allow for nighttime ventilation throughout the home.[64]

Roof design is also an important aspect of the building envelope. It is usually the portion of the home that receives solar radiation throughout the entire day. Promoting air circulation around the roof will help to reduce the intensity of unwanted solar heat gains. Sloping the external side of the roof toward the prevailing winds can help to naturally cool its surface. Furthermore, ventilation openings in the roof should be located at different levels to promote the movement of warm air out of the space, drawing cool air into the roof cavity. Additionally, varying the size of the openings can establish fluctuations in air pressure that will promote circulation and cooling.[65] These concepts are illustrated in figure 22.

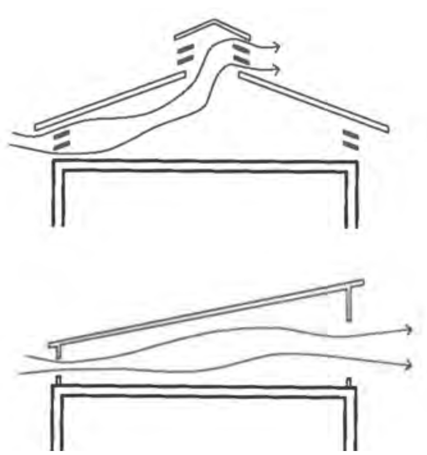


Figure 22: Roof Designs to Promote Air Circulation and Natural Cooling [Image by Holger Koch-Nielsen]

Consideration also needs to be given to the floor system and how it relates to the rest of the building envelope and the ground. Decisions about the ground level of the home and its relationship to the earth are most important when designing in hot, arid environments. For instance, in the Las Vegas area where the diurnal temperature

[64] Ibid.
[65] Ibid.

difference is high it is appropriate to maximize contact between the floor and the ground. This design choice will increase the floor's ability to store heat during the day. To further increase the thermal mass of the floor, constructing it of heavy weight materials such as stone or concrete should be considered.[66]

[66] Ibid.

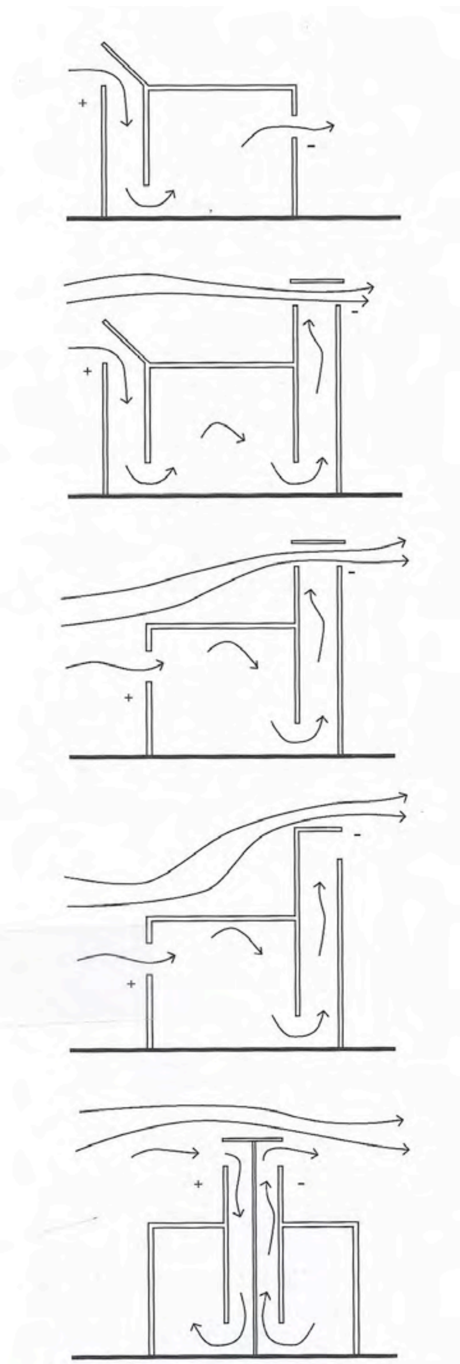


Figure 23: Wind Tower Design Principles [Image by Holger Koch-Nielsen]

Careful design of the openings in the building envelope should also occur. Openings for ventilation and daylighting can be separated from each other and function independently. Operable windows for ventilation are typically opened at night to circulate cool air and closed during the day to minimize heat gains. Designing ventilation openings to take advantage of the stack effect will help to cool down the building. This vertical ventilation method is often utilized through wind towers and centralized courtyards. As warm air rises, it is exhausted from the home, which pulls cooler air into the space. Various wind tower design are shown in figure 23. For openings that deal with daylighting, other considerations should be made. For example, direct sunlight should be minimized to reduce excessive heat gains. Diffused light is more desirable and often minimizes the effects of glare. [67]

The Surrounding Environment

The most effective designs incorporate the surrounding landscape. In the desert, these spaces are commonly unbearably hot, hostile, and unusable. Shading is

[67] Ibid.

a typical solution to making these exterior spaces more comfortable and livable. Courtyards where the floor is kept shaded for most of the day will be comfortable to occupy during that time. These will also absorb heat from adjacent rooms and radiate it out of the area into the night sky. Although the inclusion of pools and fountains has its drawbacks from a water conservation standpoint, the evaporative nature of them in courtyard spaces can help to naturally cool the air making it more comfortable. Including drought tolerant plants will have several benefits on the surrounding landscape. For one, they reduce glare that is associated with barren ground. Plants are also aesthetically pleasing and comforting to be around. Designing adjacent buildings and walls to shade each other and pedestrian circulation will have multiple benefits.[68]

Historic Vernacular Examples

The oldest desert structures throughout the American Southwest and the Middle East were made using the earth. Mud and sun-dried mud brick were preferred building materials since the earth was the only readily available material. This method of construction is considered by most Westerners to be primitive and crude. However, buildings constructed of mud provide shelter to more than 1.5 billion people worldwide.[69] Mud bricks are commonly 10x14x4 inches in size, and contain a mixture of sand, clay, straw, and water. Once mixed together, it is poured into formwork to dry. After the water evaporates, the bricks become as hard as cement. The straw helps to prevent cracking during the drying process.[70]

[68] Ibid.
[69] Bourgeois, *Spectacular Vernacular*.
[70] Vincente, "Adobe."

These homes are some of the best suited to their environment. For example, figure 24 shows the home of a Muslim leader in Mali. Notice that a few small windows and a single entry point penetrate the building envelope. This keeps the sun from penetrating into the home, keeping it comfortably cool. From the image, it is clear that the walls have a large amount of thermal mass. Wind catchers are common jutting above the roofs of most homes. Figure 25 shows how prominent wind catchers are to the skyline. The wind catchers are designed to capture even the lightest breeze and channel it into the home. After the sun goes down, the heat that was stored by the mud bricks in the sun is released. This heat warms the air surround it causing it to rise. Known as the stack effect, this phenomenon creates a draft that pulls cool breezes through open doors and windows.[71]

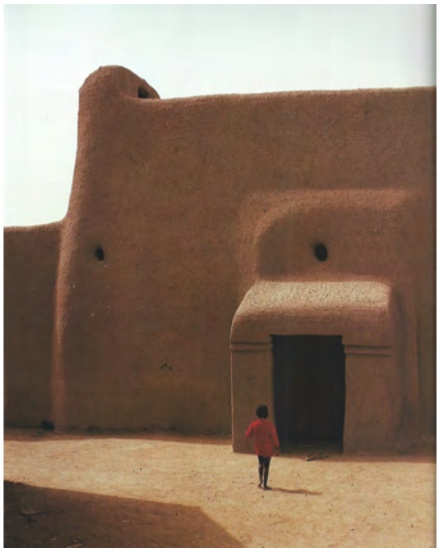


Figure 24: Muslim Leader's Home in Mali [Image by Carollee Pelos]

Figure 25: Wind catchers in Tatta, Pakistan [Image by Carollee Pelos]

[71] Bourgeois, *Spectacular Vernacular*.

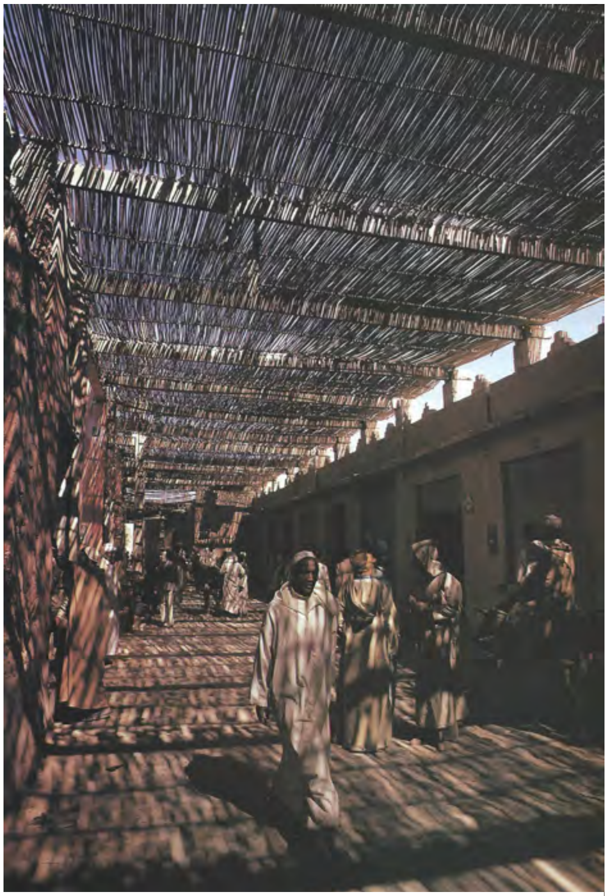


Figure 26: Shading System Over a Moroccan Bazaar [Image by Carollee Pelos]

The public realm was also considered when cities were laid out and homes were built. It was well recognized that shade was among the best methods for staying cool in the desert heat and sun. For this reason, sunshades like that pictured in figure 26 were common in public gathering areas and above market streets. Furthermore, streets were designed to be narrow and buildings tall to provide protection from the sun and desert winds.[72]


Figure 27: Taos Pueblo [Image by NPS]

Pueblos of the American Southwest speak to the vernacular architecture of the United States deserts. Pueblo Indians constructed housing complexes, now referred to as Pueblos, out of sand and earth when they settled in the deserts of the American Southwest. These

[72] Ibid.

Pueblos contained interconnected homes that each contained several rooms. Similar to homes of the Middle East, they often contain small window openings and thick exterior walls. Pueblos were built in stacked manor, similar to stairs, to take advantage of passive solar opportunities.[73]

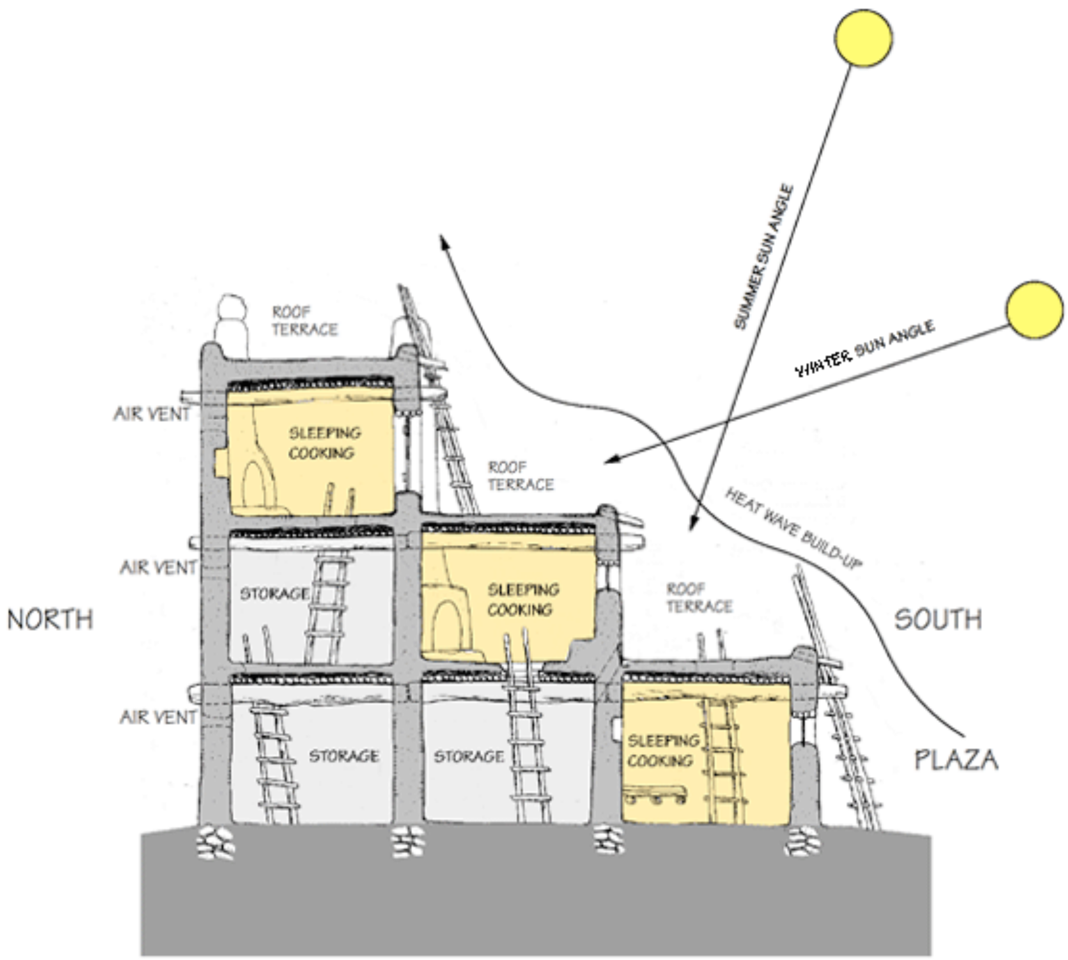


Figure 28: Section of Typical Pueblo Homes with Sustainable Features [Image by Peter Nabokov and Robert Easton]

[73] "Pueblo."

Chapter 7: Precedents

Introduction of Types

At this stage of the design process, it is vital to investigate and find precedents that cover a broad range of areas. Those shown here are mostly a collection of houses, both single and multifamily, that are committed to sustainability. Their scales and methods vary; some are sited in the desert while others are in drastically different climates. Each will be presented first on a factual basis, with many images, and then critiqued with regard to how it might contribute to the goals of this thesis.

DesertSol

DesertSol is a vacation home that was designed by the University of Nevada Las Vegas (UNLV) for entry into the U.S. Department of Energy Solar Decathlon competition for 2013. The project took second place overall, and won additional awards in the categories of market appeal, communication, and engineering. The project ultimately was also awarded LEED Platinum certification, with goals of achieving net-zero energy.[74] It is permanently on display at the Las Vegas Springs Preserve as an educational tool for the community.

Figure 29: DesertSol Exterior [Image by Mike Chino for Inhabitat]

[74] Pham, "Team Las Vegas' DesertSol Home Brings a Base Camp for Desert Exploration to the Solar Decathlon."

DesertSol is a 1 bedroom, 1 bathroom home with 735 square feet of living space that was designed to embrace the Mojave Desert environment and climate.[75]

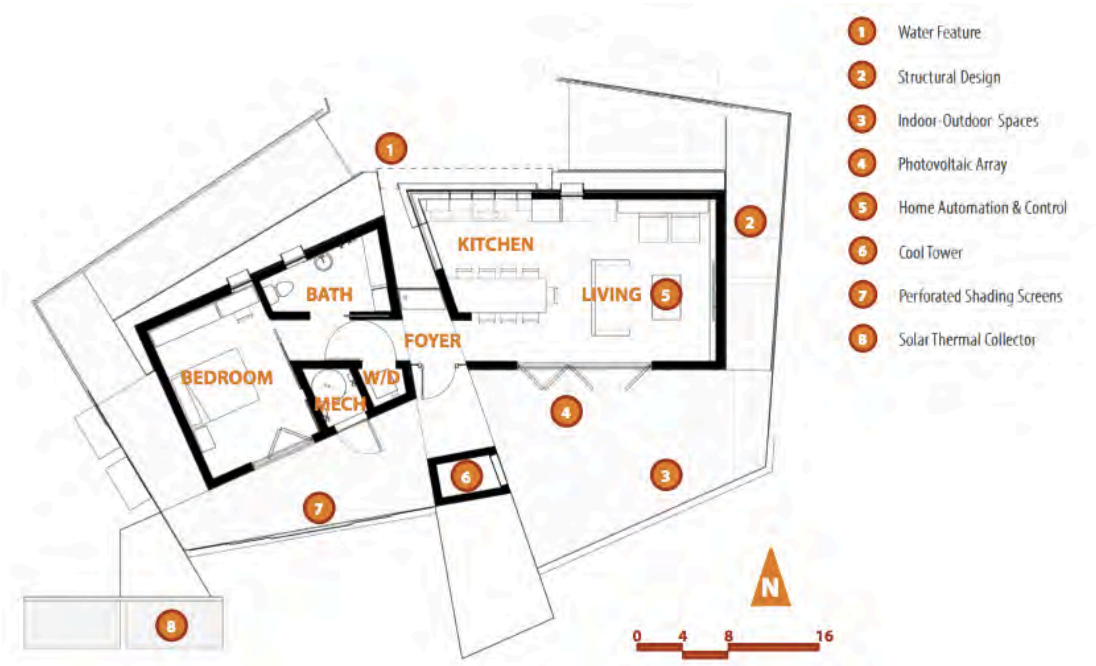


Figure 30: Floor Plan of DesertSol [Image by UNLV]

The floor plan of the home is clear, the home is divided it into two main areas. The private space to the west and the public to the east. The home has a large amount of deck space that doubles the amount of living area. The cooling tower helps to make the deck space comfortable during the summer months. It is designed to intake warm air from the top, and cool it by introducing water into it by means of evaporation. The cooled air then exits the tower and travels across the deck, passively cooling it. This is illustrated in figure 31.

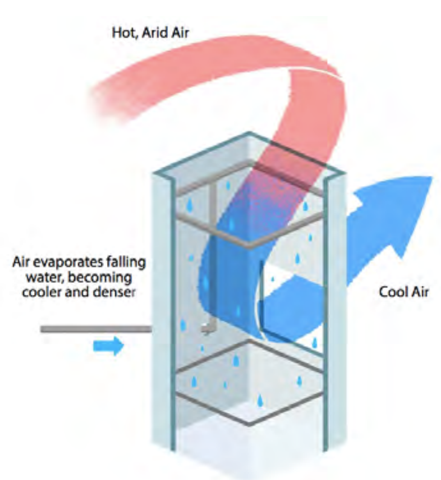


Figure 31: Diagram of the Cooling Tower [Image by UNLV]

[75] University of Nevada, Las Vegas, "DesertSol."

Sustainable features can be found throughtout the project. The structural system is among those sustainable elements. Each zone, the public and private, is built on a steel chasis with removeable axles. This allows the home to be built in a factory and transported to the site, minimizing on-site disturbances that are commonly associated with construction. DesertSol uses advanced wood framing techniques, 2x6s placed 24 inches on center, that requires 20% less material. In addition to using less wood, the thick wall allows for increased insulation which reduces the dependancy on mechanical systems.[76]

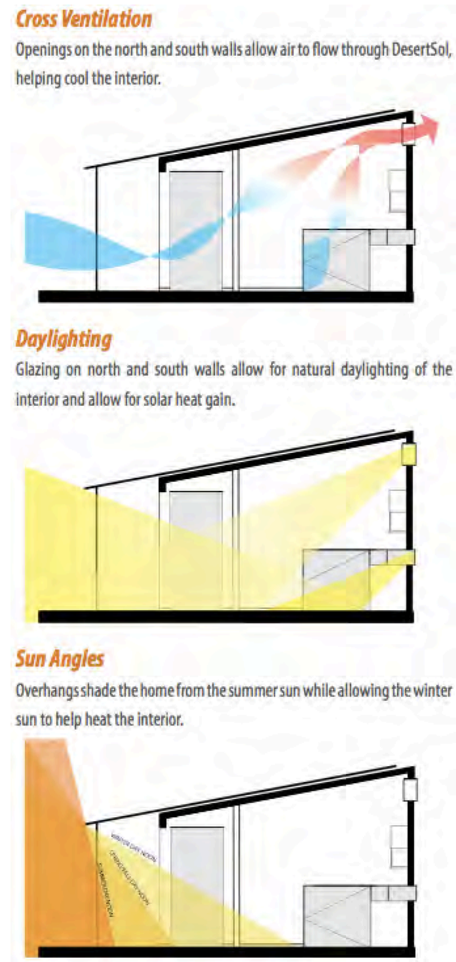


Figure 32: Diagrams of Sustainable Orientation [Image by UNLV]

The building envelope is designed to suit the Mojave Desert. The cladding system is comprised of pre-weathered wood and weathered, rusted steel panels. These materials can withstand the harsh desert conditions with minimal maintence. Furthermore, they are designed to be rainscreens and prevent heat from reaching the rest of the building envelope. DesertSol is oriented to take advantage of desireable desert

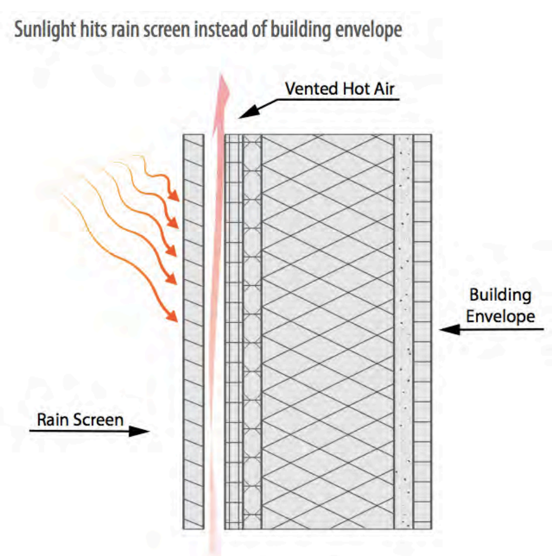


Figure 33: Diagram of DesertSol Building Envelope [Image by UNLV]

---

[76] DesertSol, "Public Exhibit Signage."

elements and minimize those that are unfavorable. For example, roof overhangs prevent unfavorable summer sun from entering the home but allow winter sun in to help heat it. As suggested earlier, windows are placed in a manor that promotes cross ventilation and natural cooling.[77]

DesertSol minizes the amount of water that it uses in several ways. One method is the inclusion of low-flow fixtures and water efficient appliances within the home. Despite the limited rainfall, the project collects any precipitation it can in a cistern to be used for irrigation when water is scarce. The home also incorporated PEX tubing which minizes the number of leaks that can occur. To heat water, DesertSol uses a solar thermal system. This system uses the sun to boil fluid that is trapped inside of small tubes. These tubes then transfer the heat to water that passes next to it. The hot water from this system is pumped through the radiant floor heating system and is also used for the domestic hot water needs. Additional sustainable features include a photovoltaic array

Figure 34: Water System [Image by UNLV]

[77] Ibid.

of 30 panels that produces 7.5 kw of power. This is more power than the home needs to operate and the rest is sent to the grid. Another feature is the home's automation system, which allows occupants to monitor energy consumption. The automation system also works behind the scenes to keep the home comfortable while maximizing the efficency of the system.[78]

This thesis and DesertSol have many common goals. Both aim to design a water conservative, net-zero energy home that is suited for the desert environment. Many of the methods for sustainability the DesrtSol used are being considered for inclusion in Prototype H_20. However, the size and several design features of DesertSol pose issues. Although it is an appropriate size for a vacation home, one bedroom, one bathroom is not practical for a family in Las Vegas. The lack of shading on the southern deck raises the question of whether it will be comfortable in the direct southern sun, even with the cooling tower providing a decrease in air temperature of 10 degrees.

Figure 35: DesertSol Exterior Close Up [Image by Mike Chino for Inhabitat]

[78] Ibid.

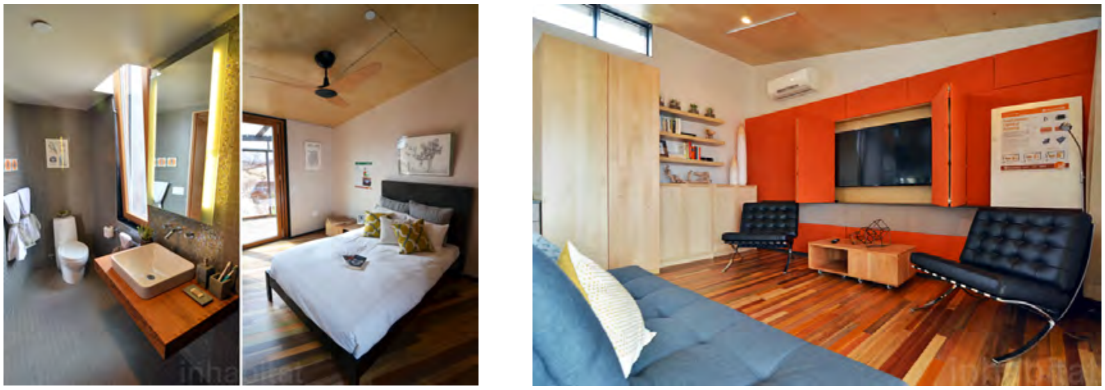


Figure 36: DesertSol Interior [Images by Mike Chino for Inhabitat]

Tubac House

The Tubac House, also known as the Tyler Residence, was designed by Rick Joy in 2001. The home is built in Tubac, Arizona, which is a desert environment similar to that of the Mojave Desert.[79] The 2 bedroom, 2.5 bathroom home is a private residence for year round use. The home takes advantage of changes in topography to protect it from the hard desert elements. To enter the home, one must ascend a staircase into a courtyard. The courtyard sits in the void created by the V shaped house and the retaining walls. The residence separates public and private spaces, with shaded outdoor spaces as the link between them.[80] The home is constructed using traditional wood framing with cast-in-place concrete foundations and retaining walls. The exterior cladding is

Figure 37: Tubac House [Image by Jeff Goldberg]

[79] Architectural Record, "Tyler Residence."
[80] New, "TUBAC.house."

weathered steel panels that match the surrounding desert.[81] Tubac House was designed to highlight the natural landscape that encompasses it; the rooflines mimic the mountains in the distance and frame the client's favorite peak. Window openings were designed to frame views, as opposed to optimizing breezes.[82]

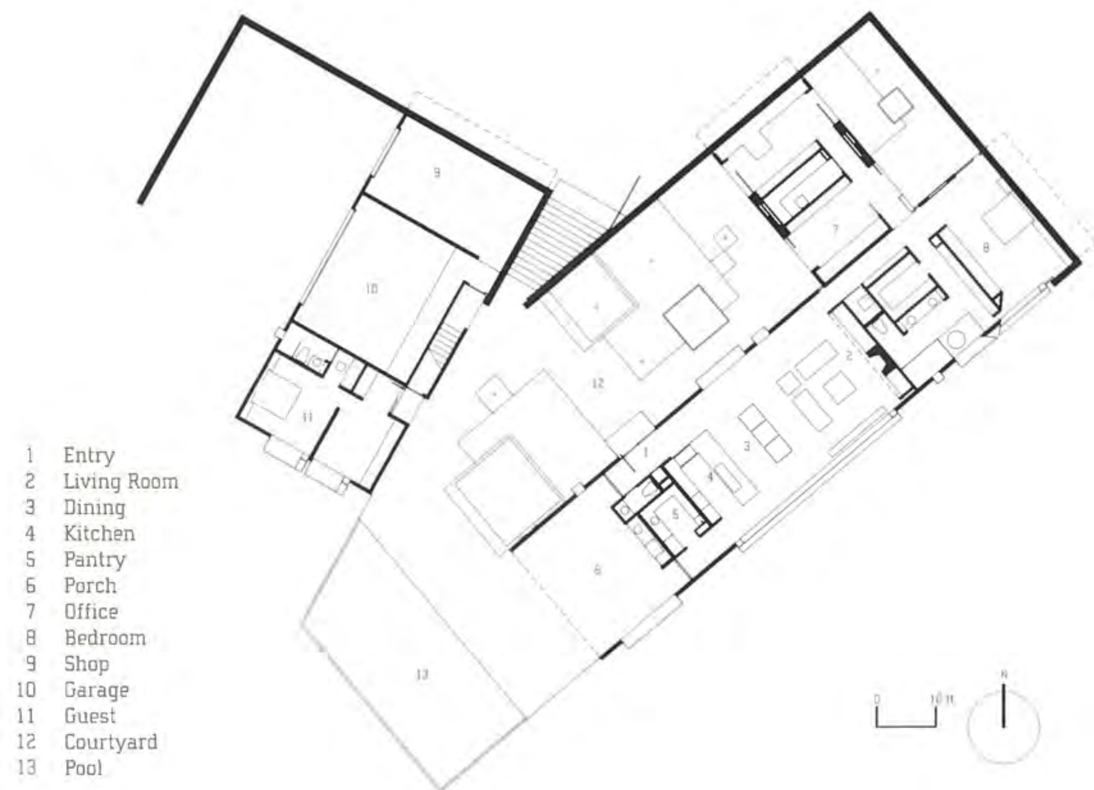


Figure 38: Floor Plan of Tubac House [Image by Rick Joy Architects]

The Tubac House has a few characteristics that align well with the goals of this thesis. The first is that the home is designed specifically for the desert landscape. The home offers several shaded outdoor spaces that drastically increase the amount of living space. The V shaped design with the courtyard in between is similar to a initial design being considered for this thesis of a U shaped home with central courtyard. Burying a portion of the home into the ground to take advantage of the earth's

---

81 Architectural Record, "Tyler Residence."

82 Joy, *Desert Works*.

thermal properties is also of interest. With 2 bedrooms and 2.5 bathrooms, the home is more appropriately sized for a small family than DesertSol. While the design has many strong features, the Tubac house is not very concerned with sustainable design. The home disregards the importance of solar orientation to mitigate heat gains, nor does it take advantage of opportunities for natural ventilation. For example, openings were placed to accommodate specific views rather than air circulation. As with every design though, compromises always need to be made.

Figure 39: Section Through Courtyard and Main House [Image by Rick Joy Architects]

Figure 40: Shaded Courtyard [Image by Jeff Goldberg]

Figure 41: Living Room and Kitchen Corridor to Porch [Image by Bill Timmerman]

Copper House

Copper House is a sprawling 8,000 square foot residence in Las Vegas, Nevada. The home was designed by Las Vegas firm AssemblageSTUDIO and completed in 2009.[83] The firm's goal is to design homes that are suited for the desert environment and not the glitz and glamour of the city.[84] Copper House has 5 bedrooms and 6 bathrooms spread over 3 levels that cascade down a hillside. This terraced method allows for daylighting opportunities throughout each level of the home. The walls surrounding the ground floor are constructed of rammed earth, which provides thermal mass to help regulate high diurnal temperature changes. Windows were designed to maximize natural ventilation. The pool acts as a humidifier for the dry desert air. As warm air passes over the pool the water that is evaporating cools it before it enters the home. Roof overhangs, louvers, other parts of the home, and

Figure 42: Copper House Exterior [Image by Drew Gregory]

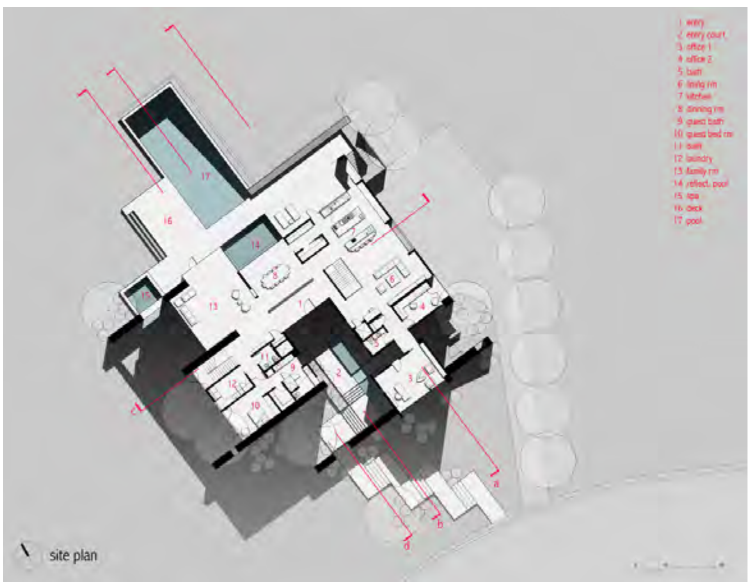


Figure 43: Main Level Floor Plan [Image by AssemblageSTUDIO]

---

[83] ArchDaily, "Copper House."
[84] AssemblageSTUDIO, "Inspiration."

window placement are designed to allow for natural daylighting without direct sunlight that would cause the home to overheat.[85]

Copper House is a useful precedent for several reasons. The first is that the home is located in the Las Vegas Valley and was designed by a firm that is committed to designing appropriately for the desert climate. Using drought tolerant plants to shade the exterior façade is a great method to make the landscape aesthetically pleasing and water conservative, while keeping solar radiation from directly hitting the exterior. Rammed earth construction is beautiful and a long lasting structural material that is being considered for this thesis project. Investigation will be done to determine the practicality of moving earth from the site to build the home into the landscape, and then using the removed earth in the building of structural rammed earth walls. Copper House shows that rammed earth is a viable option in the Las Vegas area. The aesthetics of this material are reminiscent of traditional desert dwellings made of the earth. The pool is both a positive and negative attribute. Although the evaporation of pool water cools the air before it enters the home, the pool can lose almost a gallon of water a day as a result. Historically though, pools and water features have been a widely used method for cooling desert homes and interior courtyards.

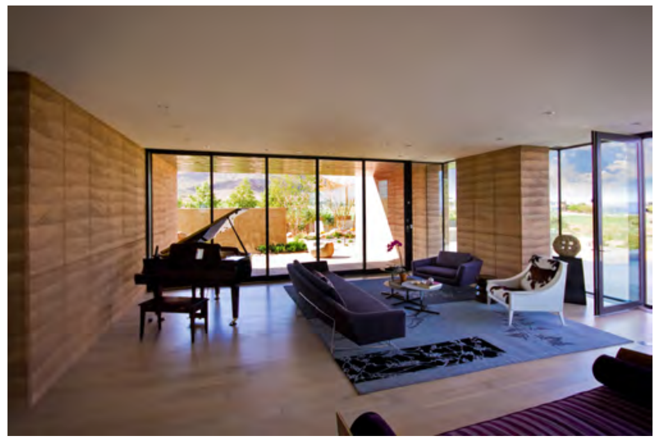


Figure 44: Living Room [Image by Drew Gregory]

[85] ArchDaily, "Copper House."

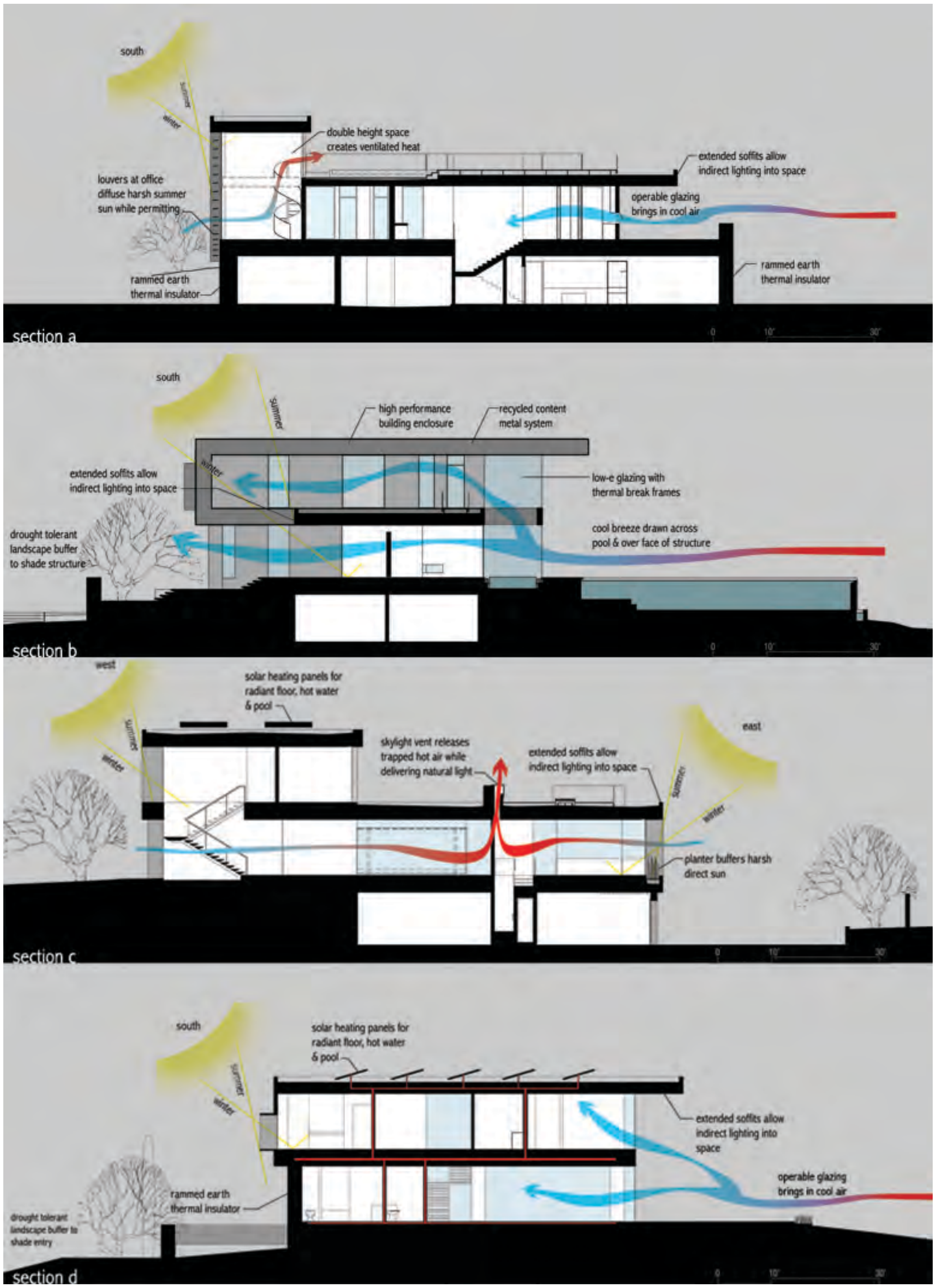


Figure 45: Sustainability Sections [Images by AssemblageSTUDIO]

WaterShed House


Figure 46: WaterShed Exterior [Image by Jill Fehrenbacher for Inhabitat]

WaterShed was the University of Maryland's, winning, 2011 entry into the Solar Decathlon Competition. The 1 bedroom, 1 bathroom home was designed as a live/work residence for a couple. It was inspired by the Chesapeake Bay ecosystem, focusing on integrating the home into the landscape and encouraging the residents to be more sustainable. WaterShed features 900 square feet and 2 decks that provide additional living space. The floor plan of the home is split into 3 main areas. The plumbing area divides the public and private spaces. A butterfly roof is one of the defining elements of the exterior.[86] The home was purchased by utility provider Pepco and is on display as an educational tool.[87]


Figure 47: Structural Framing [Image by Amy Gardner]

[86] University of Maryland, "WaterShed."
[87] Boyer, "Electric Utility To Buy University of Maryland's Solar Decathlon-Winning WaterShed House."

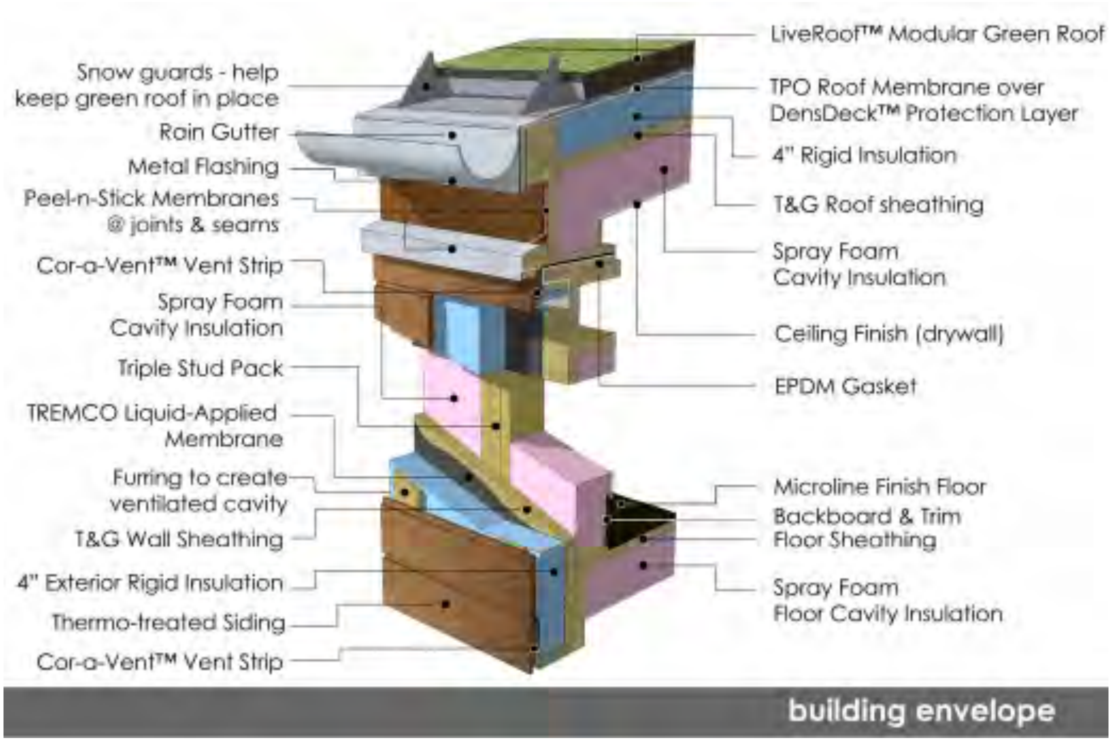


Figure 48: Building Envelope Diagram [Image by Mike Binder]

As with any Solar Decathlon project, WaterShed aims to be as sustainable as possible. The structural system is comprised of 2x6s at 16 inches on center. Load bearing structure is tripled up 2x6s at 4 feet on center. This hybrid framing system reduces the amount of lumber that is needed for construction. Additional material savings came from the modules being prefabricated in a factory. Furthermore, the hybrid system allows for fewer thermal breaks in the insulation, improving the performance of the building envelope. The envelope is 13 inches thick providing occupant comfort and weather protection throughout the year.

The walls achieved an R-value of 40 and the floors and roofs at R-50. These values are almost twice the typical American home today.[88]

WaterShed aims to conserve energy and water in a variety of ways. The first is the design of the doors and windows. They are located on each side of the home to

[88] University of Maryland, "WaterShed."

allow for natural ventilation regardless of changes to seasonal winds. Translucent wall panels in the clerestory provide natural daylighting while minimizing solar heat gains. The home is designed to produce 100% of its energy needs from solar panels. In order to achieve this goal, 42 solar panels are mounted to the roof and pergola. Each panel has a micro-converter that converters the DC power to AC. Using this method instead of a centralized converter is more efficient. As the name suggests, WaterShed's focus is on how water is used and treated throughout the home. In fact, the project treats potable, rainwater, greywater, and blackwater independently from one another. This reduces the demand on potable water because uses that do not require that standard of filtration get water from other sources. For instance, a 300

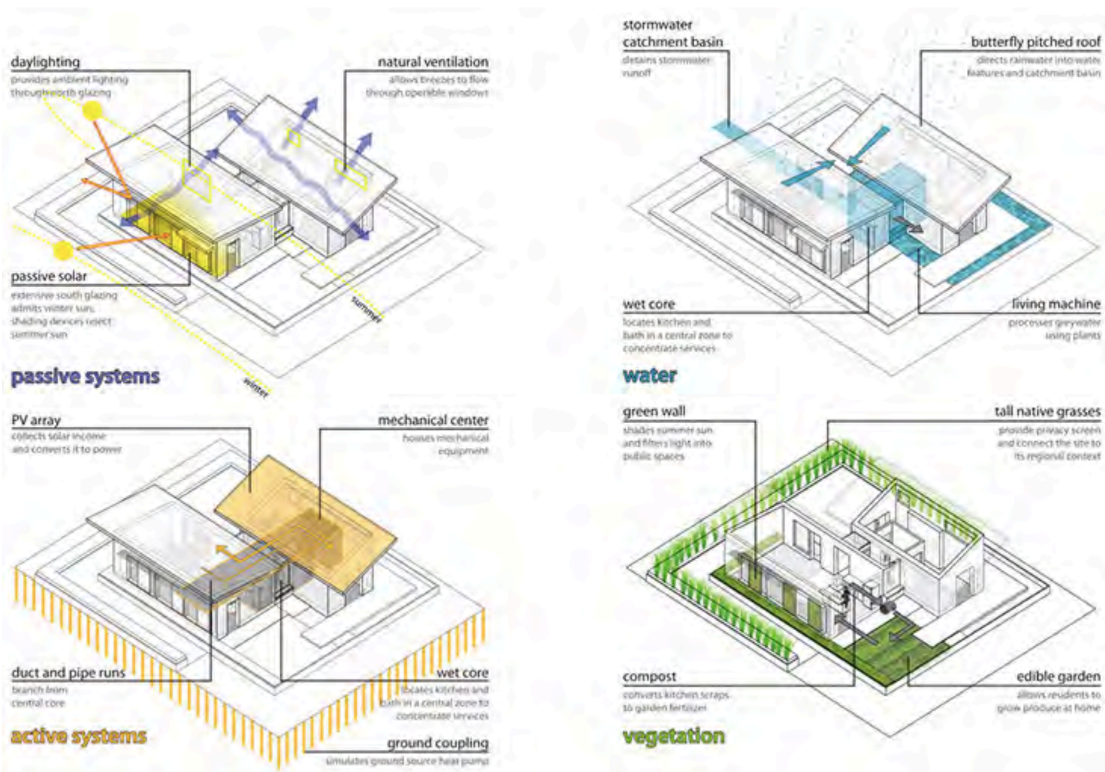


Figure 49: Sustainable Strategies Diagrams [Image by WaterShed Team]

square foot green roof on the southern module collects rainwater and diverts it for use as irrigation water. The green roof also insulates the home, reducing its temperature by up to 60 degrees. The homes uses an evacuated solar thermal collector to supply 100% of the home's hot water needs. The centralized plumbing core in the home reduces water, energy, and heat loss. Low flow fixtures in the core also reduce water use. The design feature that sets WaterShed apart from other projects is the incorporation of constructed wetlands into the design. These wetlands filter pollutants out of the water and then store clean water before it is slowly released into the surrounding landscape. The wetlands also filter the greywater from within the home's plumbing core. In all, the wetlands can hold up to 650 gallons of water.[89]

WaterShed is a beautiful project. There are several concepts that are relevant to consider for this thesis. The primary take away is how WaterShed manages each type of water (potable, grey, rain, and black) separately from one another. Recognizing this drastically reduces the amount of potable water that is used. Another consideration is the layout of the home. Establishing a centralized core for all of the plumbing makes sense as a method for conserving water, heat, energy, and initial costs. WaterShed also takes advantage of another opportunity this strategy has, teaching. By having the core overlook the wetlands it reinforces the occupants awareness of the importance of water, the poetics of it. Furthermore, there is some potential for treating greywater with wetlands in Las Vegas. In fact, there is a 12-mile long stretch of wetlands known as the Las Vegas

Figure 50: Reinforcing View from Restroom [Image by Amanda Silvana Coen for Inhabitat]

[89] Ibid.

Wash. The wash acts as a filter for urban runoff, shallow groundwater sources, reclaimed water, and stormwater.[90] In an arid environment where water is not abundant, more investigation needs to be done to determine the feasibility and benefits of a wetlands system similar to WaterShed's. A drawback to WaterShed is that it has a similar issue to that of DesertSol; it simply is not large enough to be a comfortable living space for a family.

Beddington Zero Energy Development

Beddington Zero Energy Development, or BedZED, is the United Kingdom's largest mixed-use sustainable community. It was designed be ZEDFactory and was completed in 2002 and in doing so set new standards for sustainable development.[91] Built on a brownfield, the project has 100 homes, office space, a college and community facilities. The goal of the community was to drastically reduce the amount of carbon dioxide it produced and conserve water. It wanted to change the way people lived and how they thought about the environment by encouraging them to be more sustainable. In addition to a mix of uses within the community, a mix of housing types was desired as well. For instance, the homes range from one-bedroom apartments up to four bedroom homes. Only half of the homes were sold on the open market. ¼ of the homes were designated to be low

Figure 51: BedZed Community Aerial [Image by Inhabitat]

[90] Southern Nevada Water Authority, "Las Vegas Wash."
[91] Zed Factory, "BedZED | ZED."

income and the rest are shared ownership properties. This allows for a diverse community.[92] The businesses that are located in the community range in size from very small-scale start-ups, to forty person offices. These types of businesses are often only open during the day, which leaves the community quiet during the evenings.[93]

The homes of the community have many sustainable features. For example, the windows are designed to maximize natural daylight, winter heat gains, and

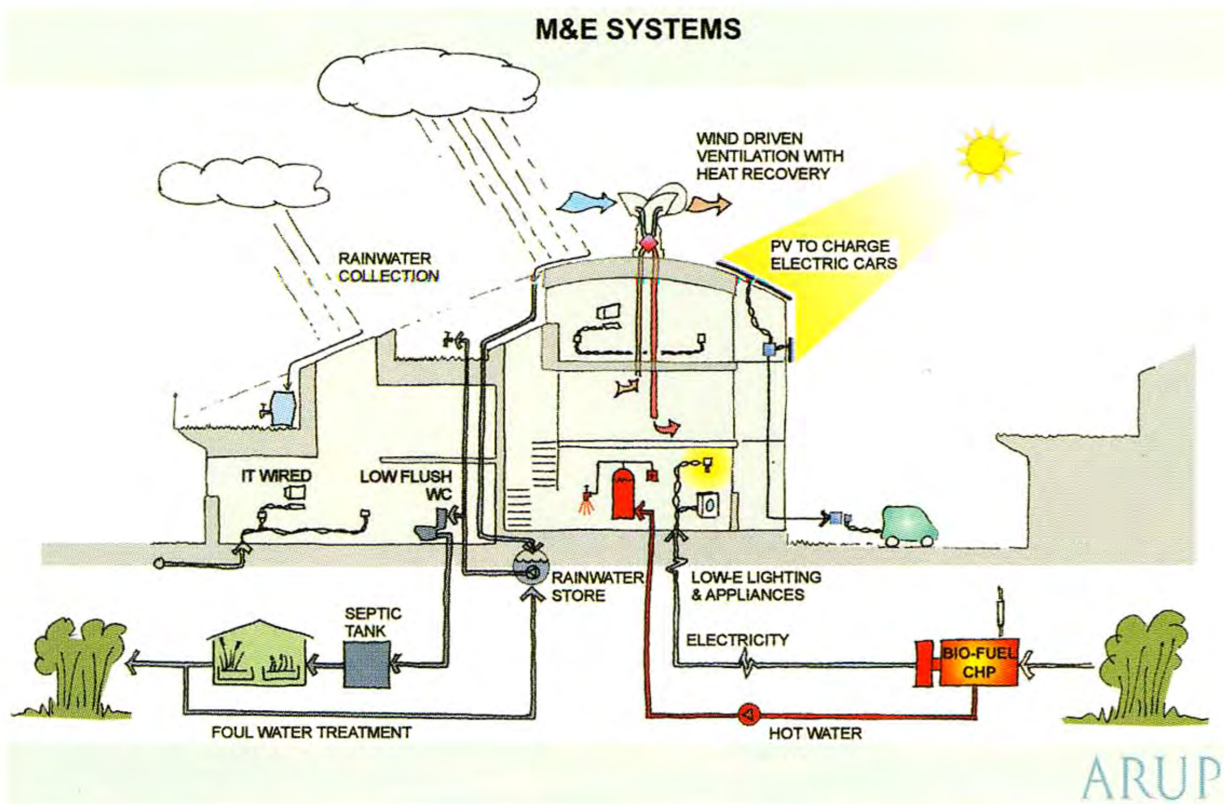


Figure 52: Sustainable Mechanical and Electrical Systems Diagram [Image by Arup]

promote natural ventilation. Natural ventilation is enhanced by the use of colorful wind cowls on the roof. These cowls draw cool air into the home, use a heat exchanger to transfer the heat from the outgoing exhaust air, and supply it to the home. Concrete floors and ceilings provide thermal mass that help to regulate the

[92] Bioregional, "BedZed."
[93] Zed Factory, "BedZED | ZED."

temperature. To conserve water, the community collects rainwater for use in toilets and irrigation. Low flow fixtures and water conservative appliances are also incorporated in the design. Easy to read water meters are installed in each residence which allows occupants to monitor their water use. A PV system on the roof and incorporated in the southern facing windows provides a portion of the electrical needs for the community. The system is grid-tied so that excess electricity can be supplied back to the utility grid. Construction materials were locally sourced and reclaimed as much as possible.[94]

The BedZed community achieved their goal of setting new standards for sustainable living. For example, the community used 45% less energy than conventionally built neighborhoods nearby. The community also achieved a 58% reduction in water use. Furthermore, residential car use was reduced by 65% with residents choosing to bike, carpool, or car share. BedZed residents recycle more than twice of the national average. The social environment of the community is better than surrounding areas as well. In fact, 84% of residents say

Figure 53: Pedestrian Pathway [Image by ZedFactory]

[94] Bioregional, "BedZed."

that their quality of life has improved since moving in. The sense of community is very strong at BedZed, with residents knowing an average of 80% of their neighbors.[95]

The BedZed community is a great precedent if the thesis project takes the aspect of designing the neighborhood and a home within it. Attached housing fits well in the desert environment, as each house has fewer exterior walls exposed to sunlight. Furthermore, they could provide for shade for each other and the public realm between them. This would be different than BedZed, which designed the homes to limit or eliminate shading of other buildings. Incorporating water meters that each resident can easily see is a smart way to encourage conservation. It is also clear that BedZed is a thriving community that has a distinct sense of place, and a goal of sustainability.

Therme Vals

The Therme Vals are a bath and spa complex located in Graubunden Canton, Switzerland. The Therme Vals was designed by Peter Zumthor and opened for operation in 1996.[96] As a bath complex, Therme Vals offers a different perspective on water. The bath complex aims to reconnect occupants with the ritual of bathing that was prominent many years ago. The building is about the poetic nature of water and the occupants' senses and

Figure 54: Exterior Therme Vals [Image by ArchDaily]

[95] One Planet Communities, "The Prototype: BedZED."
[96] ArchDaily, "The Therme Vals / Peter Zumthor."

perceptions of it. A series of baths greet the occupant with different experiences. For example, there is a “sound bath”, “fire bath”, “flower bath”, and “cold bath”, as well

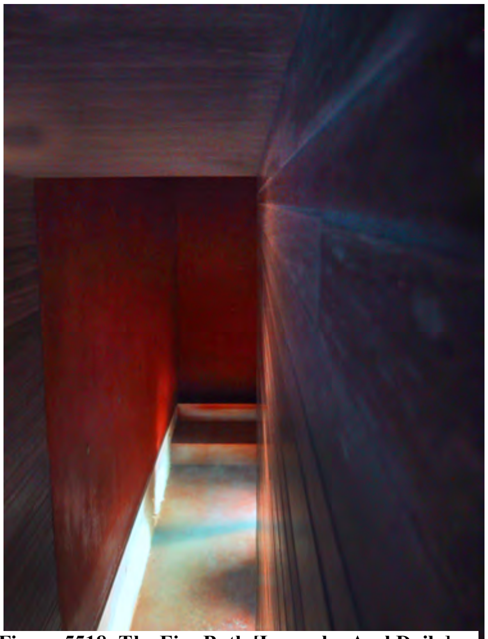


Figure 5518: The Fire Bath [Image by ArchDaily]

as an indoor and outdoor bath. These baths feature different temperature water in addition to variations in room dimensions and means of access. Some baths are only large enough for a single person and focus the occupants’ thoughts inward, while the large outdoor bath connects occupants back to nature. There are also steam showers that introduce the occupants to another phase that water can take.[97]

The Therme Vals is a precedent worth investigating for its appreciation for water as a design element. It is all about embracing water and its unique properties. For this thesis, designing a home that includes some of these elements can help to celebrate water and make the residents more aware of their consumption of the limited resource. Although they were chosen for aesthetic reasons, the Thermal Vals incorporate locally sourced materials, vegetative roofs, and thermal mass into the design.

Figure 56: Outdoor Pool [Image by ArchDaily]

[97] Hauser, *Peter Zumthor--Therme Vals*.

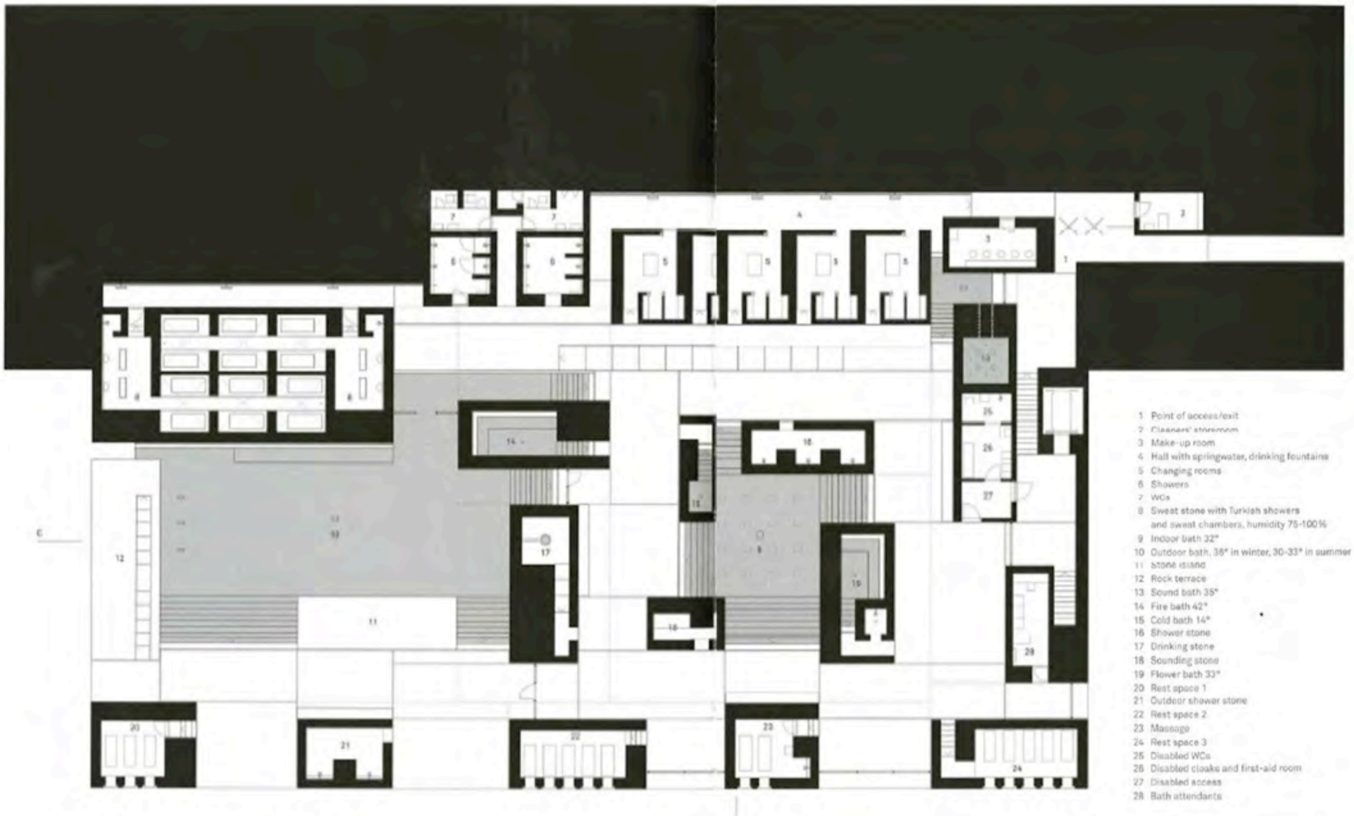


Figure 57: Floor Plan of Therme Vals [Image by Peter Zumthor]

Chapter 8: Potential Design Approaches

Potential Design Paths

Having conducted research on a wide range of topics and buildings surrounding this thesis, several different design opportunities have been brought to light. The common thread between them is the design of a desert prototype house that uses water and energy as conservatively as possible.

The initial concept for this thesis was to design a stand-alone home that met the criteria listed above. Although it would have a specific desert site near Las Vegas, the site would not be a driving factor for the design. Choosing this design approach would allow a lot of time to get into the specifics of every aspect of the design, as well as the details about how each technological addition functions independently and as a whole to achieve water and energy conservation. A design path that would complement and enhance this concept would be to investigate the prototype in a water heavy site as well. In doing so, the thesis could examine what aspects of the prototype would have to change in order to make it ideal for a wet environment versus a desert one. This would allow for the comparison of the two prototypes, resulting in a stronger argument for a return to a vernacular way of building and thinking.

Using the previous potential approach as a starting point, adaptations to the prototype also seem like a worthwhile exploration. The ultimate goal of this approach would be the same as the previous, a stand-alone prototype that is best suited for life in the arid desert. Similar to the precedents from the Solar Decathlon, this prototype would be seen as a set of modules or a kit of parts. The prototype would most likely consist of three modules, a public module containing the living and kitchen area, the private module containing bedrooms, and the wet module, which would contain the bathrooms. After designing each module, the thesis would explore how the modules are oriented and come together given varying site conditions. For example, how would the prototype function and look on a flat site versus a steep slop? What would change if the home were constrained by a site that is longer in the north-south direction than the east-west?

Thinking back to the BedZed precedent, the thesis could take the approach of designing a community. It would design a community that is as sustainable as possible and promotes residents to be as sustainable as possible as well. It would take advantage of the potential for designing the public realm to make it comfortable to inhabit in the desert. From there, the thesis would investigate and design an example of a home within the community.

It is well recognized that multifamily housing consumes substantially less water than a detached, single-family one. The design opportunity here would be to establish a new prototype for multifamily housing that has such a strong appeal to residents that it curbs the continuing trend of single-family suburban sprawl. The difficulty of this approach would be to design a dwelling that makes people reconsider living in detached housing. The public realm of this project would have to be well thought out also, since having a private yard is one of the draws to the suburbs. The site would be vital to this project, needing to offer access to public transit and spaces for recreation on site. Ultimately, the project would also aim to conserve water and energy as much as possible.

A final design approach may be to not design a house at all. Instead, design a center for learning about strategies for being sustainable in the desert and celebrate water at the same time. Initial thoughts lead to a public pool house or desert visitor's center. The concern with a visitor's center is that the Las Vegas Springs Preserve already provides educational opportunities for sustainability. Furthermore, visitors to Las Vegas are not the target audience for what the thesis hopes to achieve.

The most exciting opportunity currently is the kit of parts or module approach to the prototype that can adapt to variations in desert sites. Although this has potential to get to the neighborhood scale, which would have variations in plot sizes and topography, to some extent, it would likely be too great of a task to design at three scales within the timeframe of this thesis.

Additional Design Considerations

There are a few ideas that have the potential to enhance the design of the prototype and include a poetic aspect of water while maximizing the water conservation.

Solar stills are intriguing and hold potential to produce potable water in the desert. These devices mimic the natural water cycle to create clean, drinkable water from contaminated sources. The system works by using the sun to heat contaminated water to the point that it evaporates. The water vapor then condenses into clean, drinkable water when it comes into contact with a cool surface. The potable water is collected and available for use. A section of a solar still can be seen in figure 58. It seems plausible that this technique could be integrated as part of the roof structure,

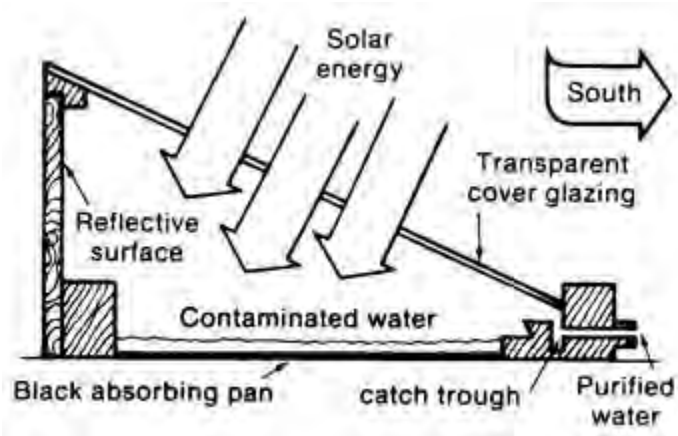


Figure 58: Section of a Solar Still [Author Unknown]

using a portion of the home's greywater as the input water source. A small scale solar still will be built in the coming weeks to explore this idea further.

In developing countries, people are using water bottles filled with water and a small amount of bleach to illuminate their homes. This inexpensive strategy has allowed them to have light in their otherwise dark homes. This system takes advantage of the physical principle of refraction. In this case, the water in the bottle refracts sunlight into the room below. It is capable of emitting light that is equivalent to a 40 or 60-watt light bulb.[98] This concept has potential to be used relatively unchanged as a light source during the day; eliminating the need for electrical lighting during that time. Also, it could be designed as a regular reminder of the importance of water, perhaps manifesting itself as a series of small lights located behind a transparent water supply line. The thought is that the light quality would change each time the fixture associated with that supply line was in use.

Non-Considerations

There are several concepts that this thesis recognizes but wishes not to address. The first the practicality of living in the desert, where water is already scarce and the issue is intensifying. Some may argue that the city of Las Vegas and others like it in the desert should simply not be allowed to grow in population or even be abandoned all

[98] Kuruvilla, "Brazilian Mechanic Creates Light Bulb Using Water, Bleach, and a Bottle."

together. Although this is a viable option for water and energy conservation, doing something like that would be near impossible given political aspects of the United States. Furthermore, with increases in sea level rise, a net-zero energy, water producing home in the desert valley may be a long-term solution when the ocean overtakes cities on the coasts. On a more local scale, continued reform of water policies and methods for distribution and treatment could be considerations, especially because they will most likely continue to evolve with growing sustainability issues. Besides what this thesis has already discussed early in the chapters regarding water and energy conservation strategies, it will not recommend changes to policies or incentives.

Chapter 9: Design Approach

Overarching Direction:

As the research progressed and the design phase began, the concept and goal of the project became clear. This thesis would focus on the design of two homes for the Las Vegas, Nevada region that are net-zero energy and as water conservative as possible. The assumption was that they would be a part of a larger, sustainable development; as an alternative to standard developer models. For this reason, it was vital that the designs have mass appeal, maintains affordable, and is easily replicable. To reach a broader market, two "Desert Dwelling" versions were developed.

Strategies for Water Conservation:

Throughout the research phase of the thesis, it became clear that there were several different strategies that should be deployed to conserve water. These strategies, for the most part, are not associated with the architecture of the home. Rather, they can be applied regardless of its final form. The first, and perhaps easiest piece, is to select plumbing fixtures that use the least amount of water possible. For example, a standard showerhead can use as much as 2.5 gallons per minute (gpm). By using Niagara's Tri-Max showerhead, Desert Dwelling will only use 0.5 gpm.[99] By selecting Niagara's Stealth toilet, the amount of water per flush can be reduced to 0.8 gallons; in contrast to 2 gallons for standard toilets.[100] To further water savings, Desert Dwelling toilets will be flushed using greywater from the adjacent sink fixture.

[99] "Tri-Max 3 Showerhead."
[100] "Stealth .8 GPF Toilet."

The final strategy for conserving water is by "creating" it by incorporating solar stills on the roof. The stills, which will be supplied with greywater from the house throughout the day, will produce between 12.5 to 25 gallons of clean water, depending on the season. To verify these amounts, I built a still and sent it for testing in Las Vegas. Daily measurements were taken and the testing found the still to be 25% efficient during the winter and 50% efficient in the summer months. This will reduce the amount that the home draws from the municipal supply, resulting in the savings of water and energy associated with pumping and distributing water. Another way that the home will conserve water is by reducing energy demands. This strategy relates directly back to the concept of the water-energy nexus. Since there is a link between energy use and water consumption, reducing one will also reduce the other; the driving force behind achieving net-zero energy.

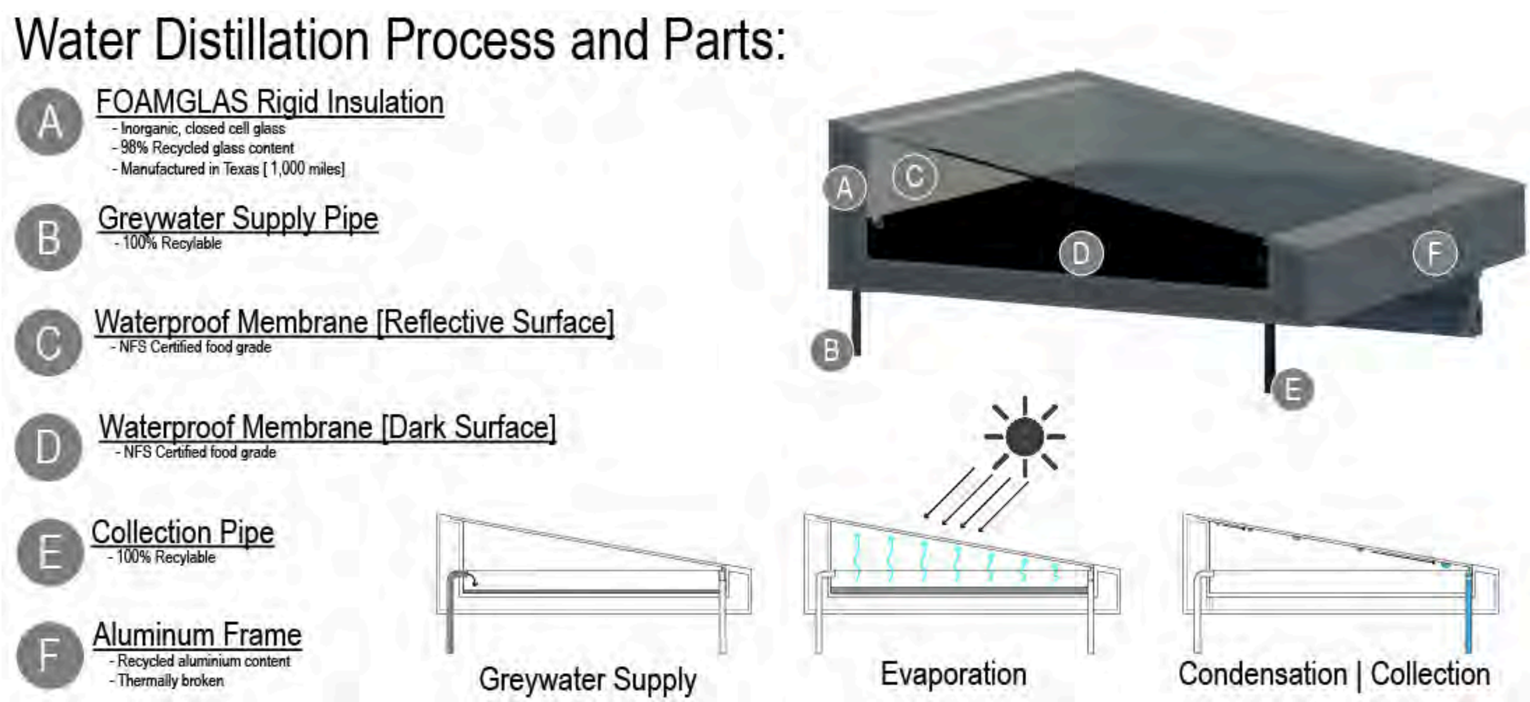


Figure 19: Water Distillation Process and Parts [Image by Author]

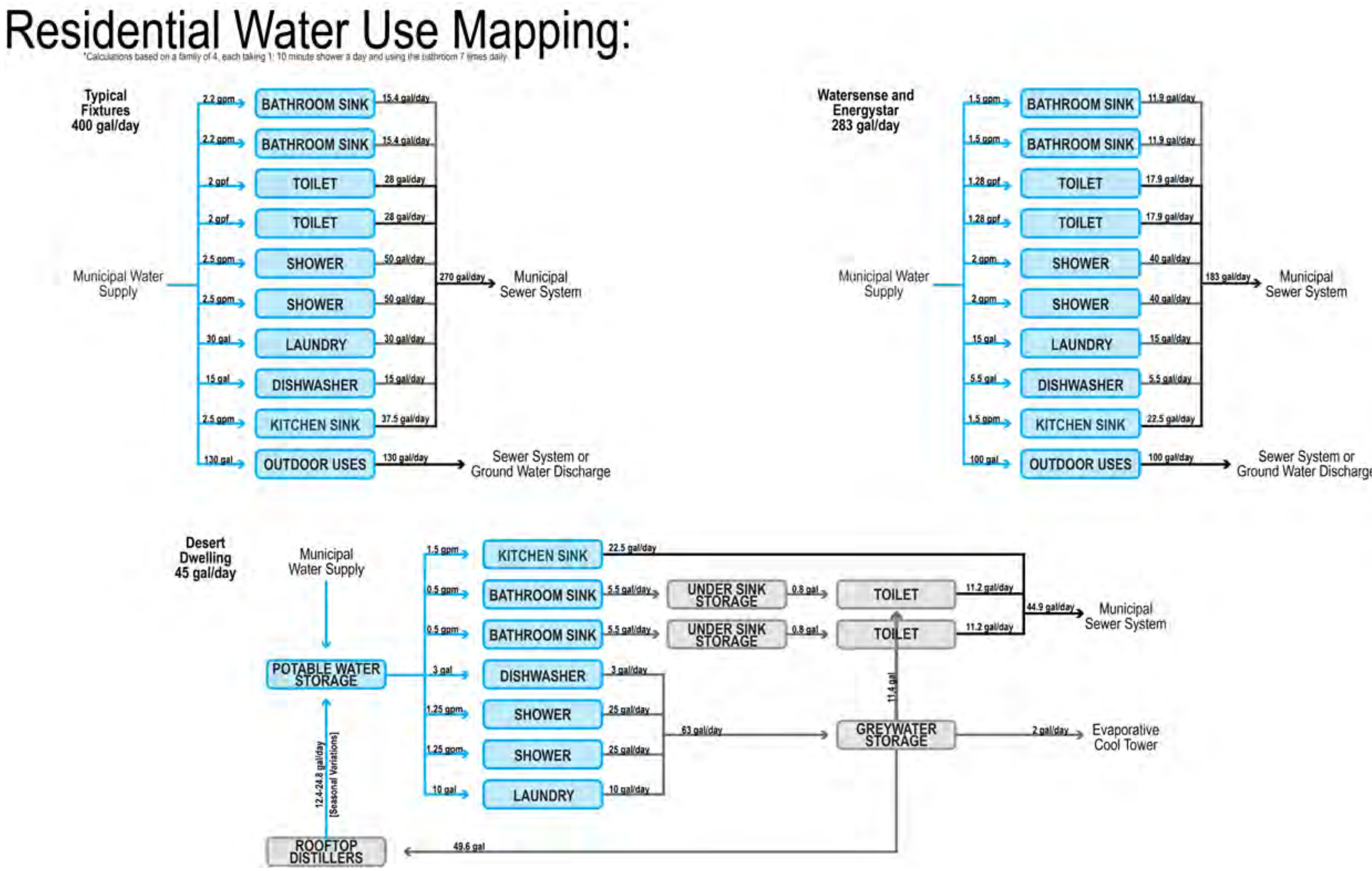


Figure 20: Schematic Water Flow and Quantities between Typical, Sustainable, and Desert Dwelling Strategies

In addition to the technical strategies for conserving water, another way to conserve water is to raise awareness of water use among the occupants and provide them opportunities to make decision and take actions to make a difference. Some of the initial strategies for this are illustrated in Figure 60. For instance, one of them was using water to cool the area in the surrounding area. Allowing occupants to control when the water is turned on/off promotes their participation and awareness of the effects of water in an arid environment. Other potential strategies included framing plants that receive their water from the home's greywater system, and making water storage tanks a focal point in the home.

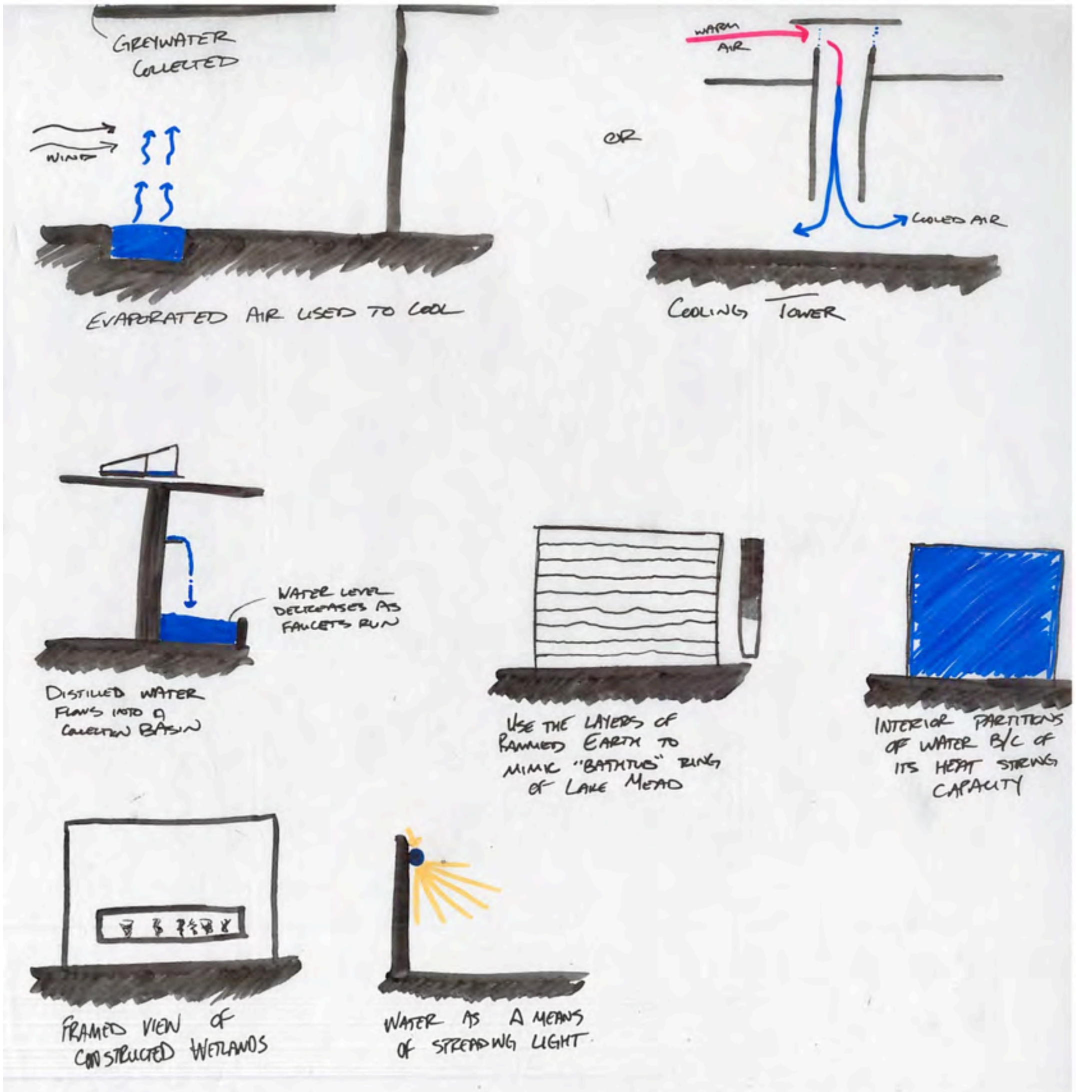


Figure 61: Initial Strategies for Raising Occupancy Awareness of Water Use

<u>Determining The Starting Point for Design:</u>

Figure 62: Typical Developer Home [Image by DR Horton]

In order to have a basis for comparison between Desert Dwelling and current building practices it was important to analyze current developments within the Las Vegas region. Figure 62 shows the typical developer home that is prevalent throughout the area. The typical home does not respond to the arid, desert climate of the region. Furthermore, the home was built without regard for solar orientation or prevailing breezes. It is also clear from the numerous deciduous trees that restricting the outdoor environment to xeriscaping was not a consideration.

Some developers are making efforts to reduce their water and energy consumption. These developers appear to approach the issue from an economic viewpoint as opposed to an environmental one: on their website, they celebrate the utility cost savings.[101] The homes achieve reductions in water consumption by using Water Sense certified plumbing fixtures and energy reductions through Energy-Star appliances, high performance system, and dual pane windows.[102]

Figure 63: Typical New Construction Home with Water Smart Certification [Image by KB Homes]

The sustainable developer homes, like the one in Figure 63, are becoming more ubiquitous. I analyzed these sustainable developer homes to better understand the program elements to determine the basis of comparison.

---

[101] "KB Home."

[102] Ibid.

	Plan 1849	Plan 2215	Plan 2431	Plan 2568	Plan 3059
Cost [In Thousands]	$220	$229	$240	$250	$265
Number of Stories	1	2	2	2	2
Square Feet	1,849	2,215	2,431	2,568	3,059
Number of Bedrooms	3 to 4	3 to 5	3 to 5	3 to 5	4 to 6
Number of Bathrooms	2 to 2.5	2.5 to 3	2.5 to 3	2.5 to 3	2.5 to 3.5
Garage	2 car	2 car	2 car	2 car	2 to 3 car

Figure 64: Comparison of Current Models [Image by Author]

To create a baseline, I used the energy modeling software BEopt, produced by the National Renewable Energy Laboratory (NREL), to analyze the typical and sustainable developer homes. BEopt is a comprehensive simulation program that can parametrically analyze home energy use and savings, in addition to optimizing them to achieve net-zero energy.[103] The software was then used throughout the design process to determine optimum window types, window areas, home orientations, amount of thermal mass, appliances, heating and cooling systems, and other components of the home. It was also used to appropriately size the photovoltaic array to achieve net-zero energy.

Floor Plan Design:

As with most design processes, one of the primary steps for determining the floor plans was examining the relationship between the public and private spaces of the home. The public spaces include the living, dining, and cooking areas. The private space is mostly comprised of the bedrooms.

[103] National Renewable Energy Laboratory, "NREL: Beopt."

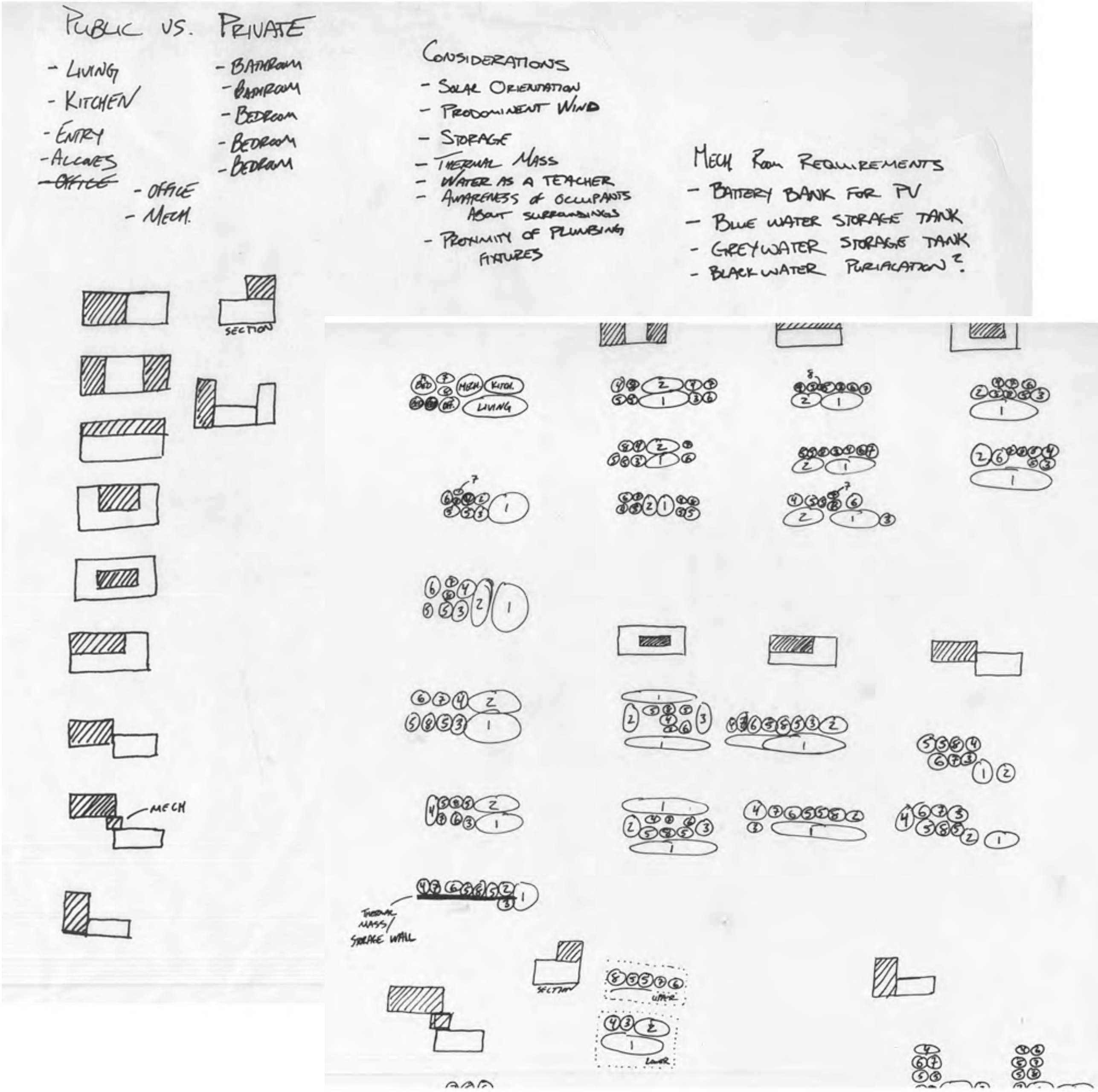


Figure 65: Public | Private and Arrangement Sketches [Images by Author]

The single story floor plan is comprised of two main modules that offer approximately 1500 ft^2 of living space with 2-3 bedrooms and 2 bathrooms. The public space includes the living, kitchen, and dining spaces, and ideally located to the south. The private spaces, including the bedrooms, bathrooms, and office, are ideally located to the north. In addition to decreasing water and energy consumption, the home aims to raise the occupants' awareness of their utility usage. An "informative entry" acts as the mediator for the home. The hope is that this will result in a change of behavior that reduces use. In order to achieve this, residents arrive at the home into an 'informative entry", where two water storage tanks greet residents (Figure 73). One tank holds the daily allotment of water for the home and the other holds filtered greywater. As a result, the occupants are constantly reminded of the ongoing water issue. A home monitoring system allows residents to see their energy consumption as well as the output from the photovoltaic system.

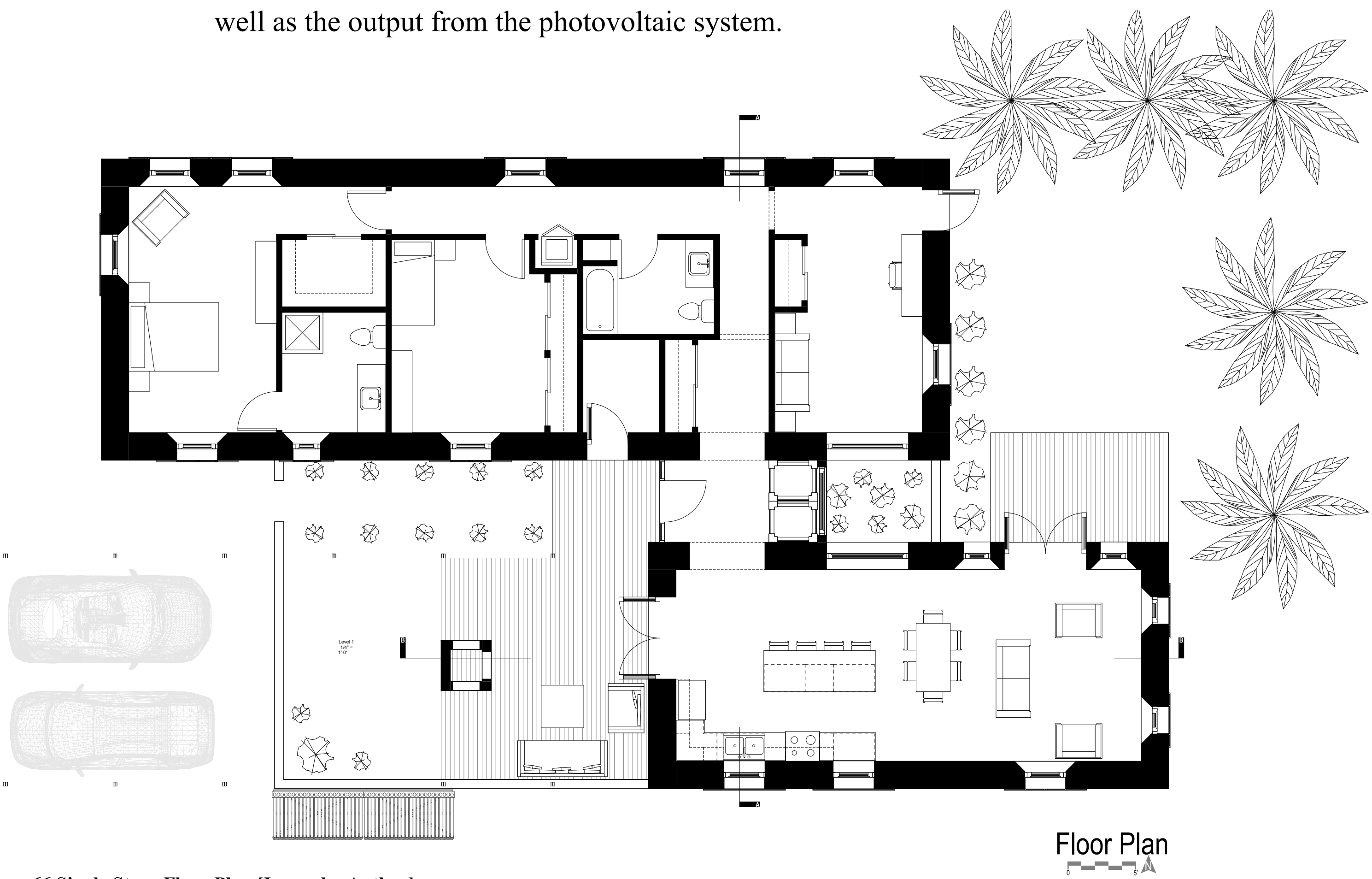
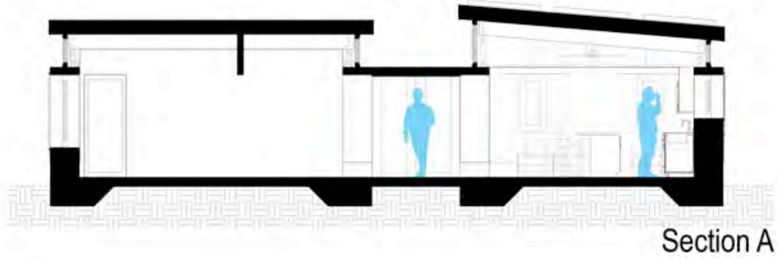


Figure 66 Single Story Floor Plan [Image by Author]



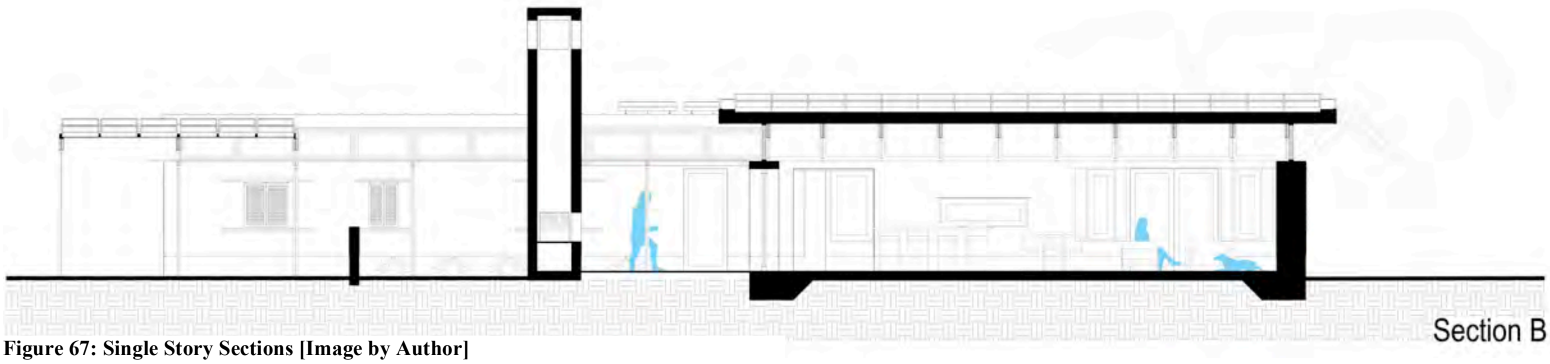


Figure 67: Single Story Sections [Image by Author]

To take advantage of winds from the southwest, the private spaces were shifted. This shift also allowed for the creation of multiple outdoor spaces so that there is a comfortable place to relax throughout the year. This is the result of the outdoor spaces being in the sun, shade, and either direct wind or shielded from it.

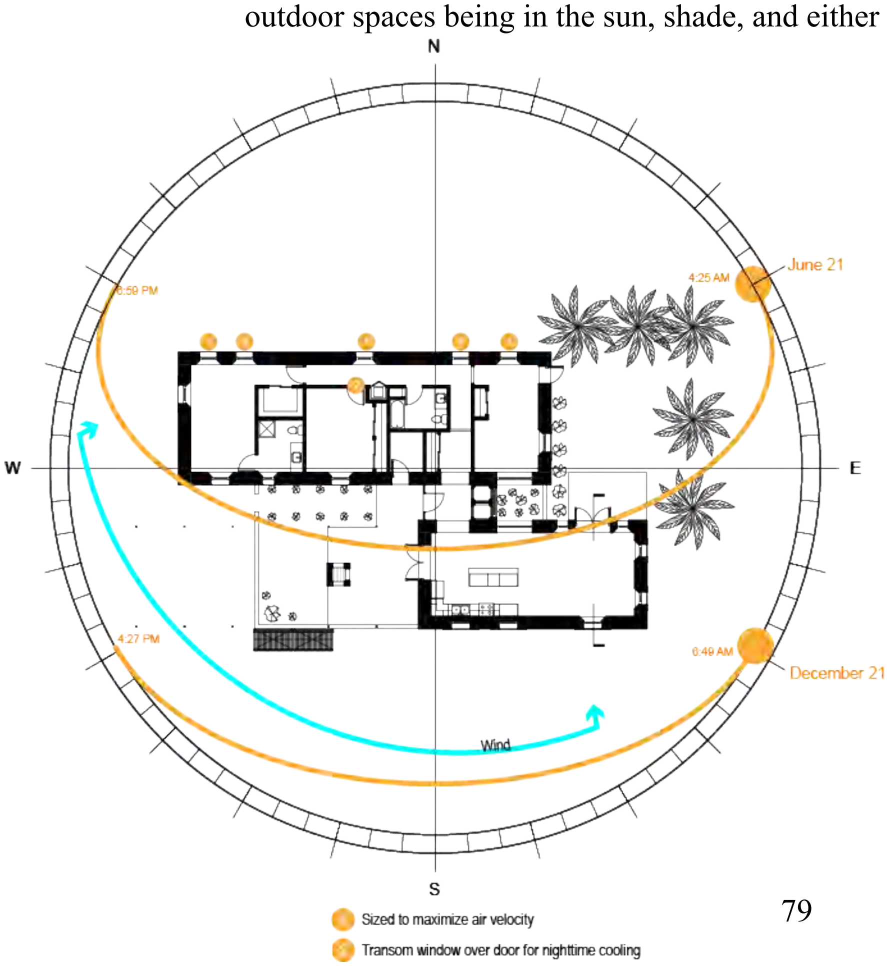


Figure 68: Sun Paths and Prevailing Winds

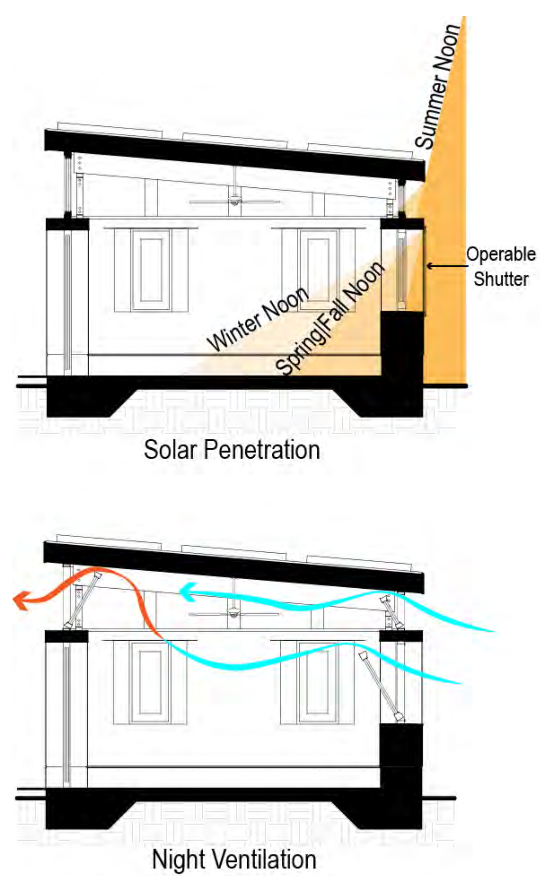


Figure 69: Sun Penetrations and Night Ventilation Sections

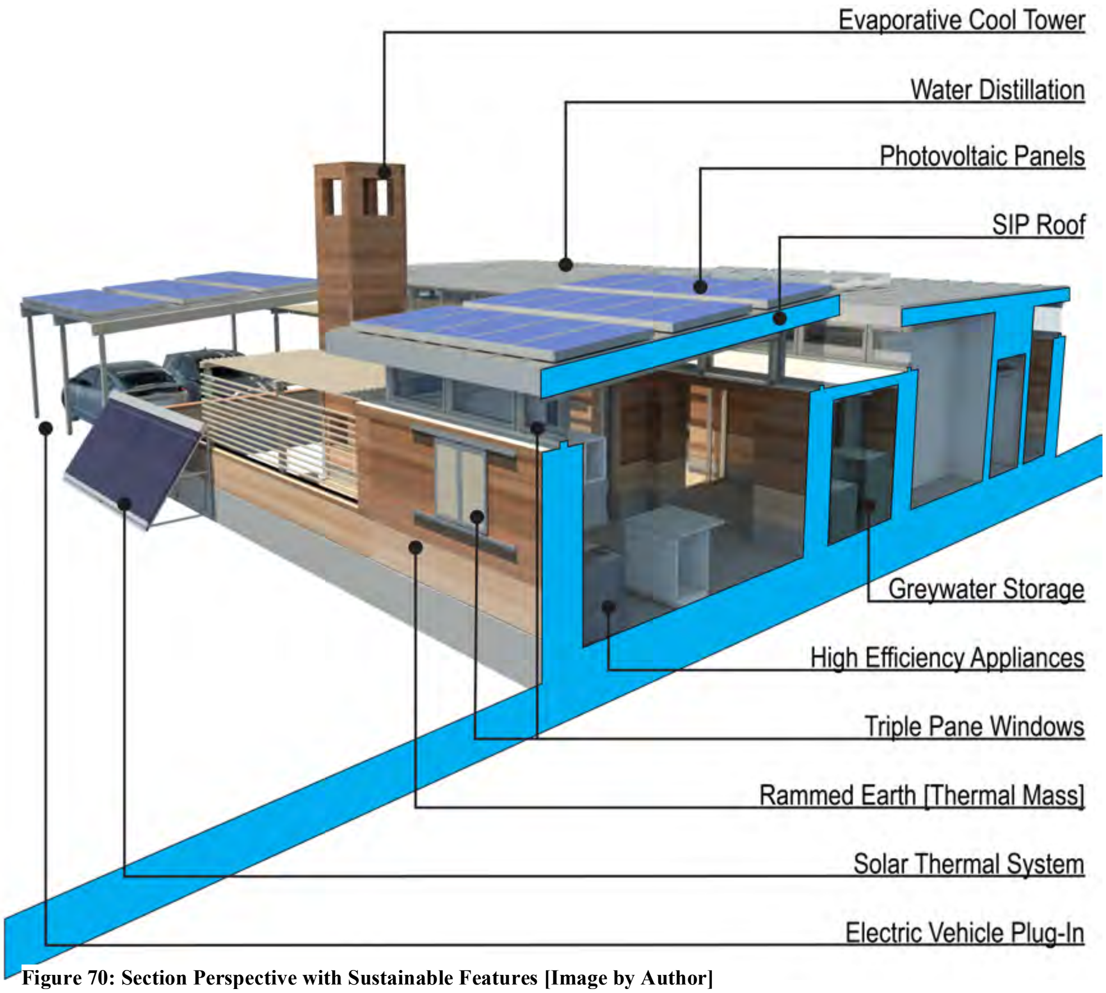


Figure 70: Section Perspective with Sustainable Features [Image by Author]

Figure 71: Front Approach to Single Story Home [Image by Author]

Figure 72: Outdoor Entertainment Space for Single Story Home [Image by Author]

Figure 73: Informative Entry with Storage Tanks [Image by Author]

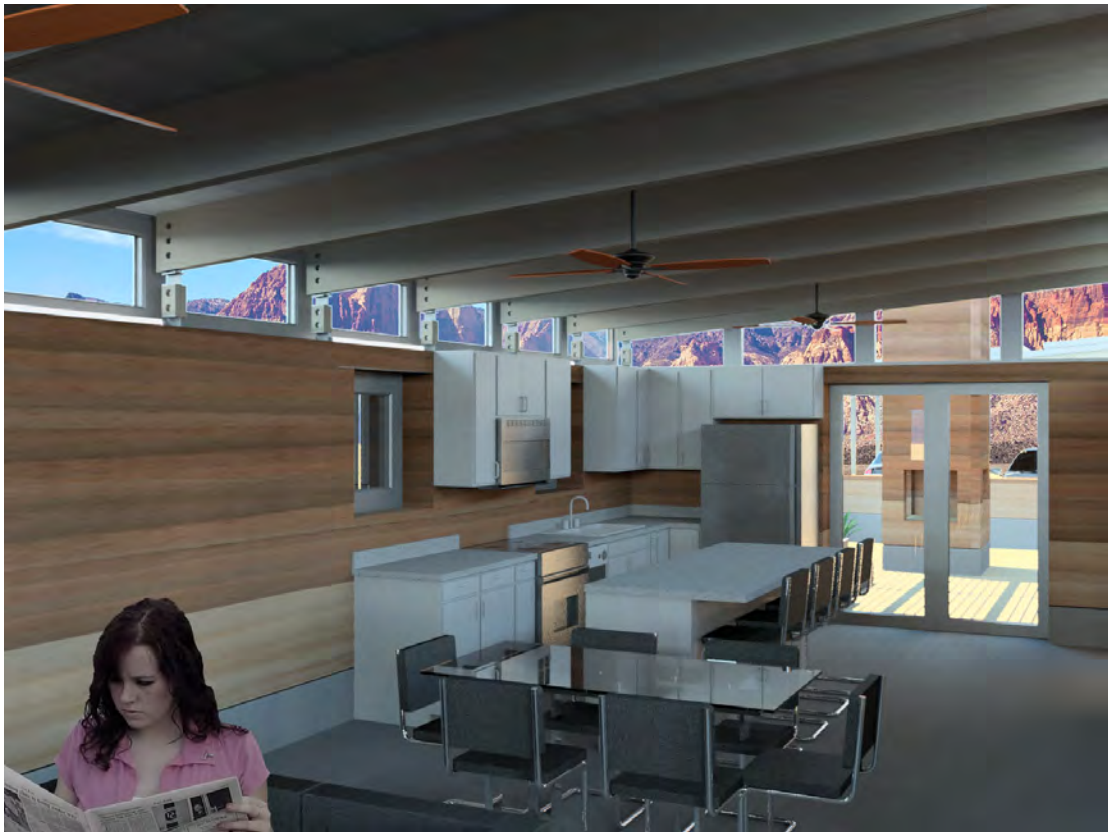


Figure 74: Living Space into Kitchen, Single Story Home [Image by Author]


Figure 75: Neighborhood from Deck of Single Story Home [Image by Author]

The two-story home is larger in size than the single story, at around 1800 ft^2, with 3-4 bedrooms and 2.5 bathrooms. This added space accommodates larger families, or multiple generations. Given that rammed earth walls are best in compression, the two-story home is limited to a straight stacked format. In addition to the larger size, the two-story home features a double height living and kitchen space that opens to a large deck, effectively enlarging the entertainment space.

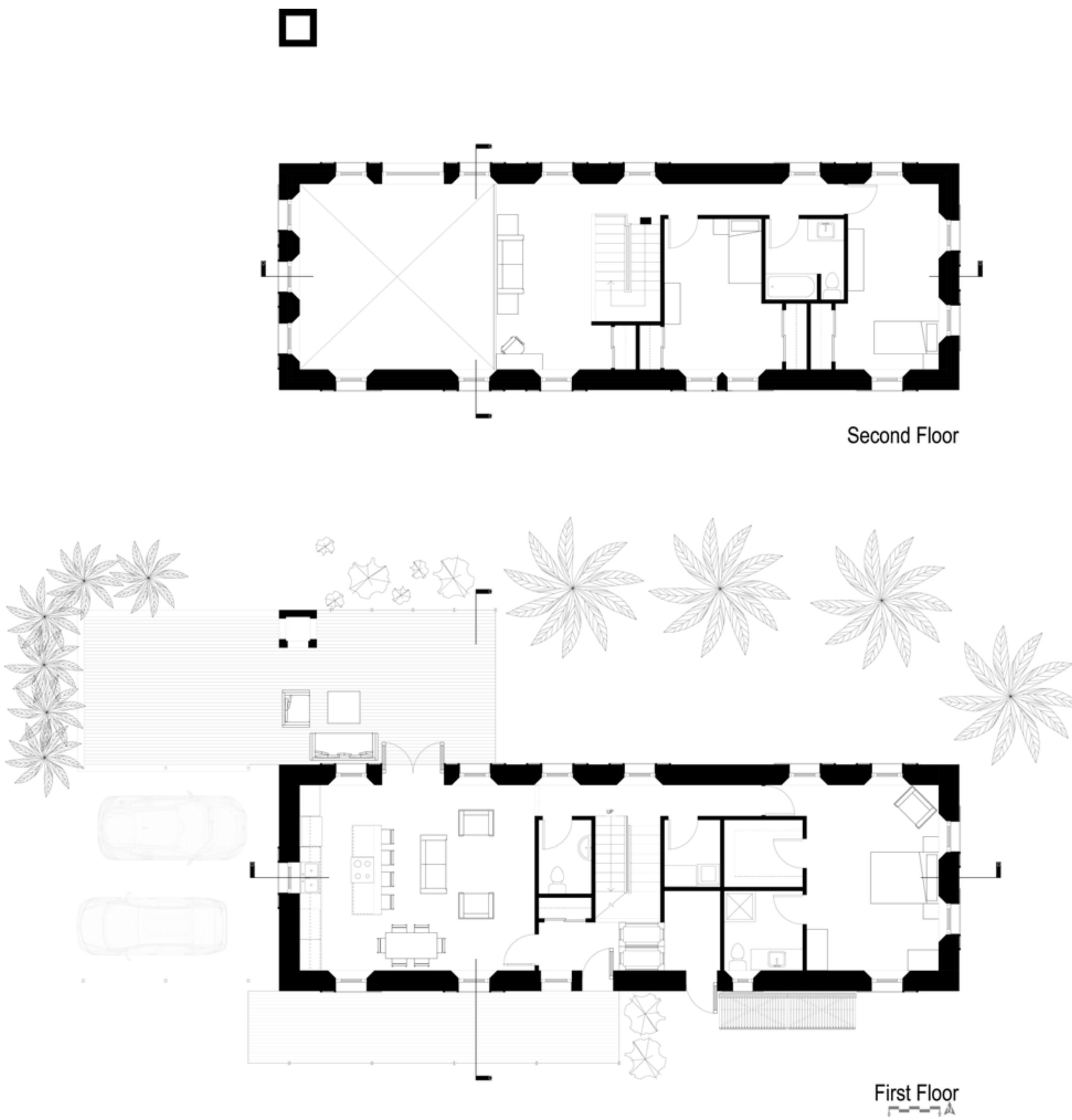


Figure 76: Two Story Floor Plans [Image by Author]

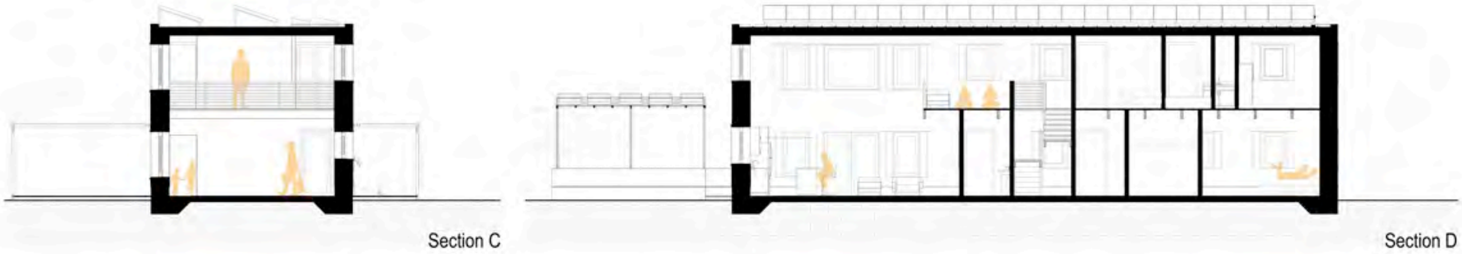


Figure 77: Sections of Two-Story Home [Image by Author]

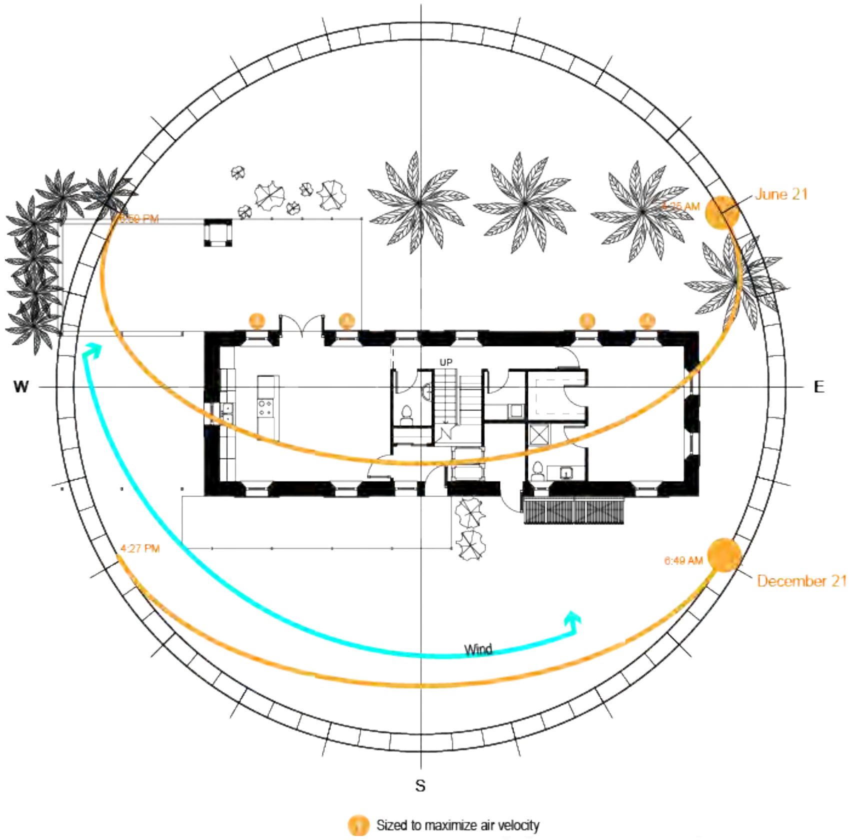


Figure 78: Sun Paths and Prevailing Winds

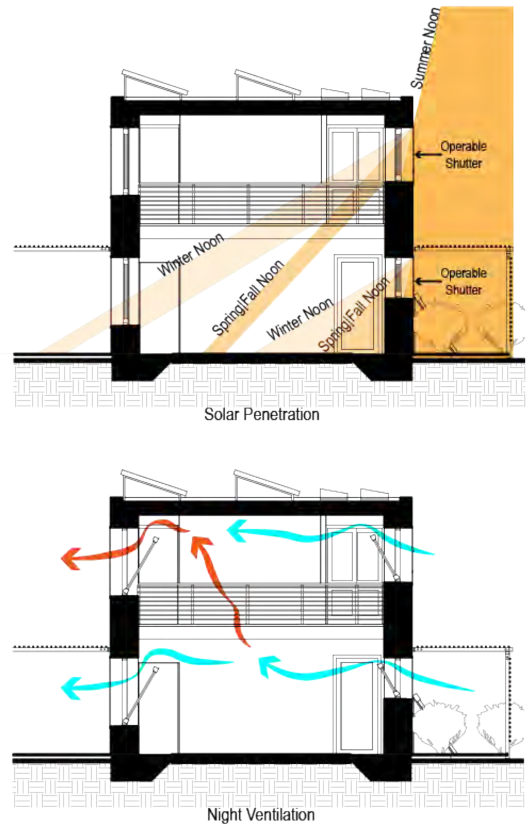


Figure 79: Sun Penetrations and Night Ventilation Sections

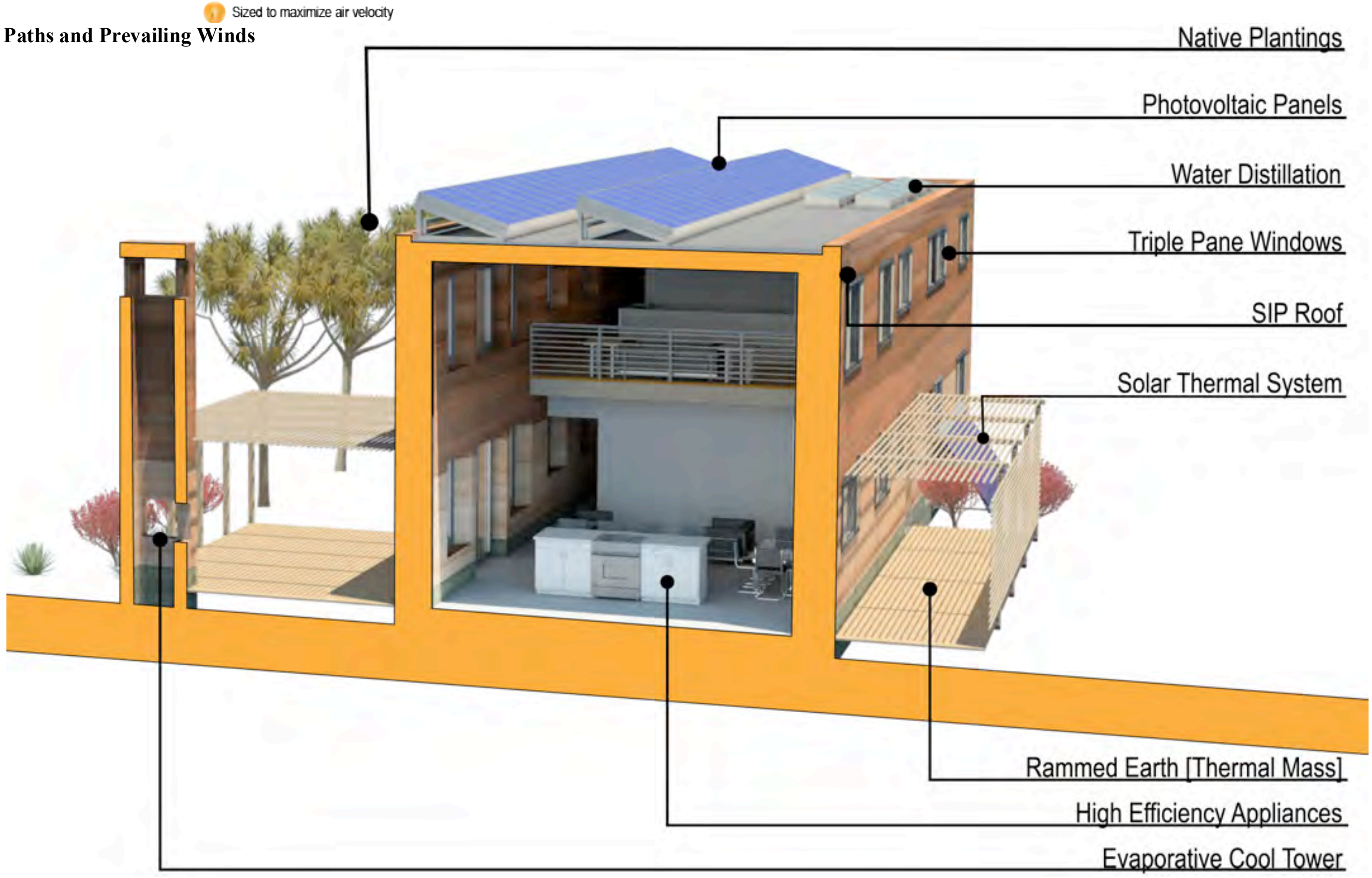


Figure 80: Section Perspective of Sustainable Features, Two Story [Image by Author]


Figure 81: Kitchen and Dining from Loft of Two Story Home [Image by Author]


Figure 82: Living Space of Two Story Home from Entry Foyer [Image by Author]

Determining Construction Methods and Materials:

Selecting the most appropriate and effective construction methods and materials throughout the home were critical. Consideration was given to the function, sustainability, durability, longevity, area of origin, and aesthetics for the building components. I chose rammed earth as the main building material for several reasons. First is to return to the vernacular, but use modern techniques. Building with the earth provides many sustainable benefits. For instance, rammed earth has a large amount of thermal mass and uses soil from on-site, or other local sources, which reduces the pollution associated with transporting materials long distances. Rammed earth can ensure good air quality in the home because it does not off-gas. Furthermore, it can provide a quiet environment since it absorbs sound from the outdoors. Aesthetically, I find it to be a beautiful material and by using natural dyes, one can add color variations to the layers. For the Desert Dwelling, I decided that the lower three feet or so of the rammed earth would be a bright, almost white color while the upper layers would be natural browns. I chose to do this to mimic the "bathtub ring" that has formed on the rocks around Lake Mead; hoping to remind residents of the link between their home and the water issues at a larger scale. In order to achieve a higher R-value, four inches of rigid insulation is centered between the two, ten-inch sections of rammed earth.

Early in the process I had considered to try and achieve Petal Certification under the Living Building Challenge's (LBC) certification program. This certification is among the most stringent sustainability metrics on the planet. In order to comply with the requirements of LBC, the materials used within the home must be free of chemicals found on organization's Red List. For this reason, I selected FOAMGLAS by Pittsburg Corning for the rigid insulation. This product is free of red list chemicals and materials, as it is made almost completely from crushed recycled glass that has been made into closed cell, rigid panels. The product is manufactured in Texas and is 100% recyclable at the end of its life.[104,105] The roof, and floor framing where applicable, is comprised of 2"x12" CLT lumber. This structural material was chosen for several reasons. The first is that the adhesive used to laminate the wood is free of red list chemicals. Furthermore, the manufacturing process uses 30% more material from each tree than standard manufacturing processes. In addition, trees are harvested from a FSC certified forest in Canada.[106] As a product out of Chibougamau, QC, Canada, it is at the maximum range allowable by the LBC criteria; at 3,000 miles.[107] The main roof structure is built of structural insulated panels (SIPs). These panels are comprised of closed cell insulation centered between wood sheathing. The limited possibility for air infiltration, as well as the thickness of the panels, provides the roof with an R-value of 50. The panels are 100% recyclable at the end of their life, and are manufactured in Payson, Arizona; 340 miles away.[108] The finished roofing material is a galvalume, standing seam roof. Light in color, the roof will reflect the desert sun, keeping the home cooler. Furthermore, solar panels can easily be mounted to the roof, which has a 25-year lifespan and can be fully recycled afterwards. It is a product from California, 200

---

[104] Pittsburg Corning, "FOAMGLAS® Pittsburgh Corning."
[105] International Living Future Institute, "Declare."
[106] Nordic Engineered Wood, "X-Lam | Cross Laminated Timber."
[107] International Living Future Institute, "Declare."
[108] "Premier SIPs | Residential SIPs Framing Systems | SIP Homes."

miles away.[109] Since doors and windows are the least insulated aspect of the building envelope, it was vital to make them as efficient as possible. For this reason, triple pane windows were selected. The selected windows can open as casement windows to optimize natural ventilation, and hopper windows to provide ventilation with added security. 85% of the window system can be recycled at the end of its life. The doors and windows have thermally broken aluminum frames made with recycled content and come from Valley, Washington; 1,000 miles away.[110] Materials for the flitch columns are steel with recycled content, as well as dimensional lumber from FSC certified forests in California. A majority of the selected materials were found via a website associated with the LBC, www.declareproducts.com. The website has a database for products in all divisions that are either red list free, or red list compliant. It also provides information about the origins of the raw materials, as well as the manufacturing locations. Per the website, it is an “ingredients label for building products.”[111]

---

[109] International Living Future Institute, “Declare.”
[110] “Cascadia Windows & Doors.”
[111] International Living Future Institute, “Declare.”

1 **Solar Panel**
- Monocrystalline solar cells at 18% efficiency
- 25 year warranty
- Locally sourced from Bombard Renewable Energy

2 **Rooftop Distiller**
- 100% recycled aluminum frame

3 **Standing Seam Metal**
- Durable | 25 year life span
- Light colored to reflect sunlight
- Allows mounting of solar panels
- 100% recyclable
- Manufactured in California [220 miles]

4 **Structural Insulated Panel**
- R-50 insulation value
- 100% recyclable
- Manufactured in Payson, AZ [340 miles]

5 **Flitch Column**
- Recycled steel content
- FSC certified lumber from California [400 miles]

6 **(2) 2'x12" X-Lam CLT @ 48" O.C.**
- FSC certified lumber from Chibougamau, QC [3,000 miles]

7 **Steel Angle Lintel**
- Recycled steel content
- 100% recyclable
- Manufactured locally

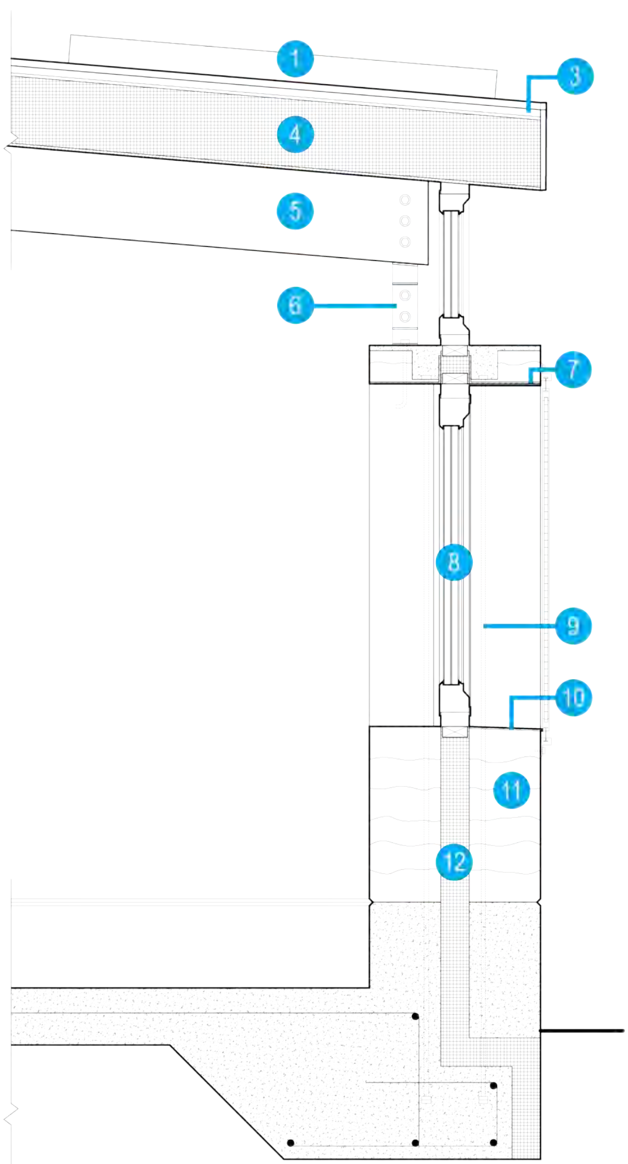
8 **Triple Pane Window**
- Thermally broken aluminum frames
- Casement and hopper functions for maximum ventilation and security
- Manufactured in Valley, Washington [1,000 miles]

9 **5/8" Threaded Rod in Aluminum Sleeve**
- recycled steel and aluminum content
- Manufactured locally

10 **Steel Sill**
- Recycled steel content
- 100% recyclable
- Manufactured locally

11 **Rammed Earth**
- Onsite and locally sourced
- Provides thermal mass
- Absorbs sound
- Natural material
- Low maintenance

12 **FOAMGLAS Rigid Insulation**
- Inorganic, closed cell glass
- 98% recycled glass content
- Manufactured in Texas [1,000 miles]



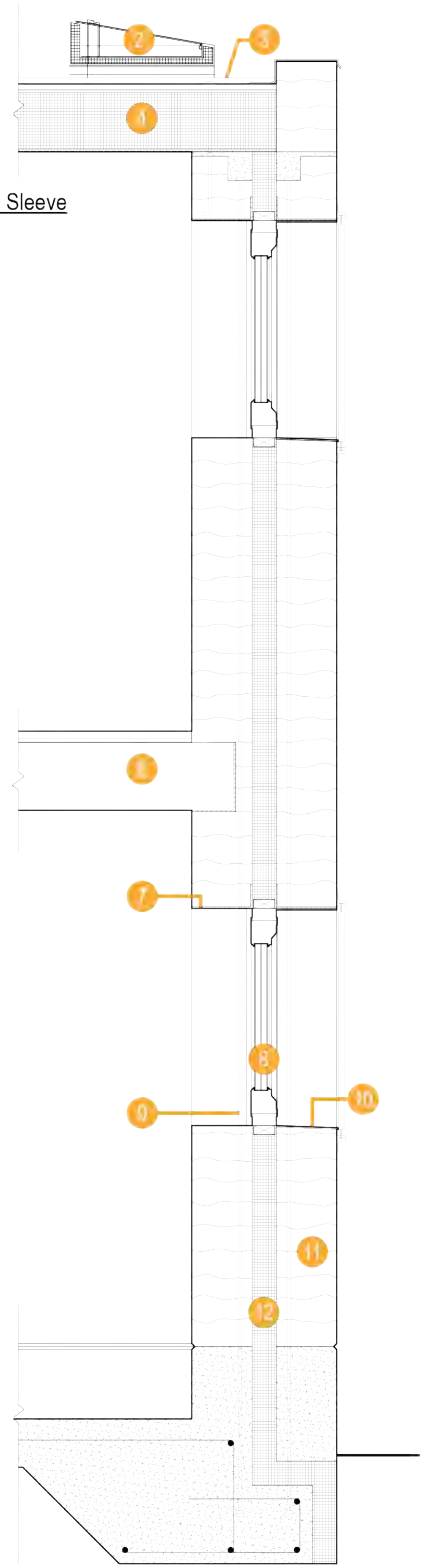


Figure 83: Detailed Wall Sections

Aggregate Savings and Long Term Potential:

As a result of the various strategies to conserve water and energy, the Desert Dwelling would consume 1/10th of the amount of water per day as a typical home would. This was based on a family of 4, each taking a 10 minute shower per day and using the toilet 7 times, which is the national average. On an annual basis, this results in the conservation of 129,575 gallons of water per house. Since the goal of this thesis was to design the next standard for development, it was important to determine the potential savings if the construction of all new homes were Desert Dwellings. In order to determine the number of new homes that are projected to be built in the future, two key figures were researched. These were the projected population growth of 0.9% annually, and the average number of people per home for the region, 3.2. Based on these values, 5,960 new homes per year to house all growing population. If this growth trend continues, constructing Desert Dwelling homes will result in a savings of 16,215,736,261 gallons of water in 5 years (by 2020). In 25 years, there would be a savings of 271,034,000,000 gallons. This is approximately the amount of water needed to fill 410,000 Olympic sized swimming pools.

BEopt was used to help achieve net-zero energy. The software was used to help determine the initial forms of the homes. After that, the floor plan was given the necessary inputs to meet local building codes. From there, the inputs were changed to equate those of the sustainable developer homes in the area. This energy savings associated with this are shown in the orange sets of bars in Figure 82. From that point, alterations to the building structure, materials, and systems were adjusted to reduce the energy use further. BEopt was then used to optimize the size of the photovoltaic array, allowing the home to achieve net-zero energy use on an annual basis.

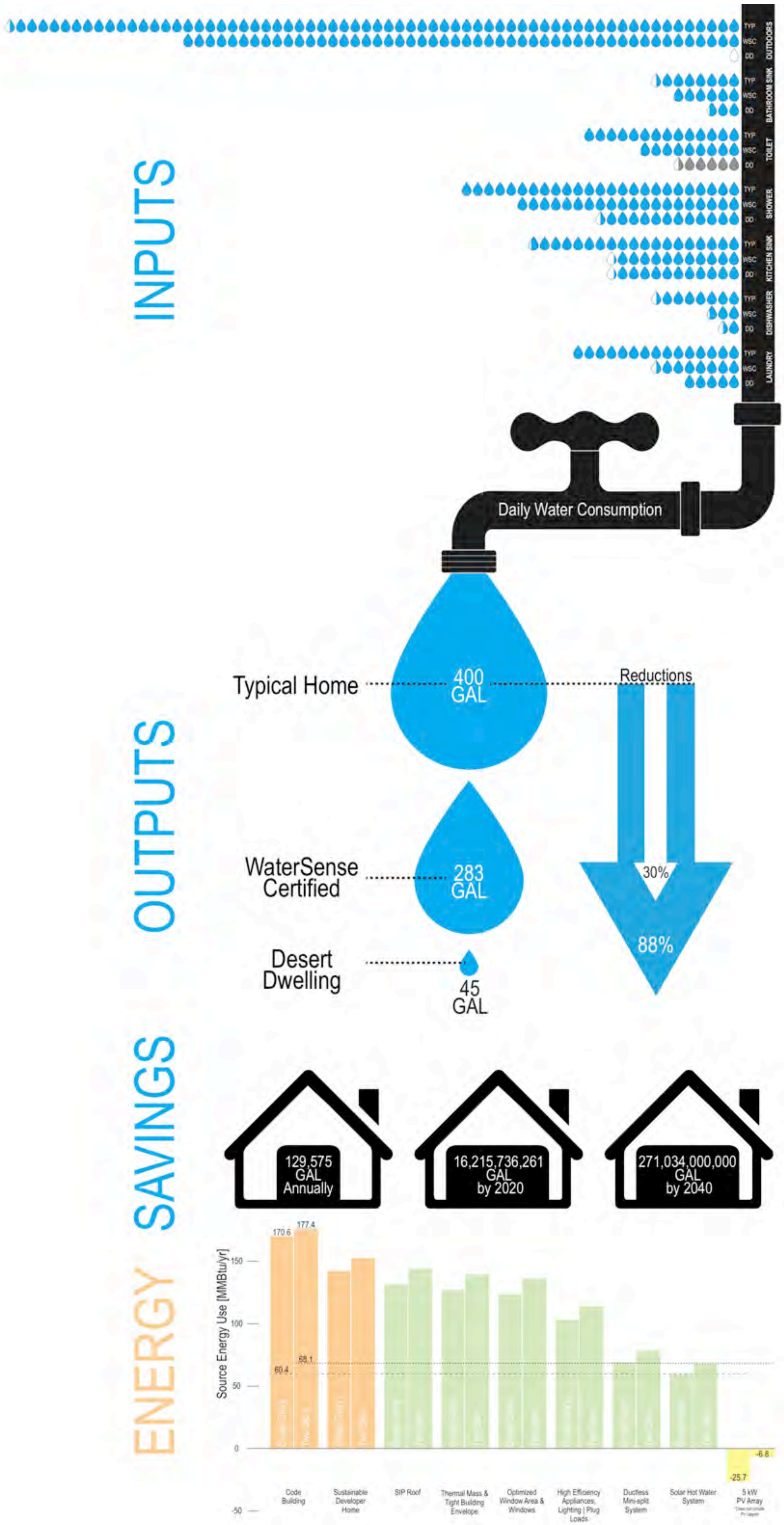


Figure 84: Daily Water Use | Potential Water Savings | Steps to Net-Zero [Image by Author]

Chapter 10: Conclusions

Public Presentation Comments:

The conversation following the public presentation was very interesting and informative. It focused much more on the issues of water conservation, settlement patterns, and the role of architects than the Desert Dwelling homes themselves. For instance, the premise of building single family homes in presumably suburban sprawl patterns as opposed to multifamily in a more urban environment was not chosen. I offered the rational that based on the research of water and energy consumption in that region, creating a sustainable single family home could yield the most improvement. The conversation continued by discussing why the homes so closely resembled that of those being built today, with regards to the program and features. Given the conversation between reviewers I was unable to remind them that the goal of this thesis was not to design a custom home, nor was it to radically change the market overnight. The idea was that Desert Dwellings are the next standard developer home, and the changes made to the program, plans, and fixtures were a stepping stone to an even more sustainable home of the future. Perhaps that home would be able to achieve net-zero water, in addition to net-zero energy. The reviewers challenged the claim of achieving net-zero energy, but given the extensive energy modeling I am confident in that claim. There was also a lively debate regarding the ethical aspects of living in the desert at all. The reviewers appreciated the depth of study behind the research and product selections.

Closing Remarks:

Overall, this thesis accomplished what it set out to do. I was able to design a series of homes that are water conservative and net-zero energy. I still have a few reservations about the potential of rammed earth walls on a mass production scale. I question if it would be more sustainable to use a different wall type, perhaps SIP panels to achieve the R-value for the walls. The polished concrete floor may provide the needed thermal mass to help moderate the diurnal temperature swings. I am confident that improvements to the design of the solar still could increase the efficiency of the system even more. One of the reviewers posed the question: what if these were moveable? She offered the idea that when the water does dry up, the homes could be relocated to a more suitable location. This is an interesting concept that would require significant redesign of the home's systems, but the overall floor plan could remain the same. I hope that this thesis inspires people to be more aware of their water and energy consumption. As for myself, I hope to continue my pursuit of sustainable, contextually, and climatically appropriate homes.

Bibliography

Allan, Tony. 2011. *Virtual water: Tackling the threat to our planet's most precious resources*. London: I.B. Tauris & Co. Ltd.

Anderson, Christopher. 2011. *Corn*. Dallas, Texas: .

Andrews, Kate. 2008. “BEDZED: Beddington Zero Energy Development in London.” *Inhabitat*. January 17. http://inhabitat.com/bedzed-beddington-zero-energy-development-london/.

ArchDaily. 2011. “Copper Haus / assemblageSTUDIO.” *ArchDaily*. February 1. http://www.archdaily.com/107357/copper-haus-assemblagestudio/.

ArchDaily. 2014. “The Therme Vals / Peter Zumthor.” *ArchDaily*. Accessed December 13. http://www.archdaily.com/13358/the-therme-vals/.

Architectural Record. 2014. “Tyler Residence.” *Architectural Record*. Accessed December7http://archrecord.construction.com/projects/residential/archives/0104TylerHouse.asp

AssemblageSTUDIO. 2014. “Inspiration.” *AssemblageSTUDIO*. Accessed December 7. http://www.assemblagestudio.com.

Associated Press. 2014. “Southwest Braces as Lake Mead Water Levels Drop.” *Mail Online*. Accessed December 4. http://www.dailymail.co.uk/news/article-2722730/Southwest-braces-Lake-Mead-water-levels-drop.html.

Atkinson, William. 2014. “The Missing Link: Increasing Public Awareness of the Interconnectedness of Water and Energy.” *Water World*, October.

Azulultramar. 2008. *Therme vals*.

Bourgeois, Jean-Louis. 1996. *Spectacular Vernacular: The Adobe Tradition*. 2nd ed. New York, NY: Aperture Foundation.

Bovill, Carl. n.d. ARCH461 LecturesIn Person.

Boyer, Mark. Electric utility to buy university of maryland's solar decathlon-winning WaterShed house
. 2012 [cited October 2014]. Available from http://inhabitat.com/electric-utility-to-buy-university-of-marylands-solar-decathlon-winning-watershed-house/.

Brewer, Michael. United states drought monitor. 2014 [cited October/28 2014]. Available from http://droughtmonitor.unl.edu/Home.aspx (accessed October 28, 2014).

Calcara, Sergio. 2012. *Shower*. Sydney, New South Wales, AU: , http://thenounproject.com/term/shower/1322/ (accessed October 29, 2014).

Camus, Felipe. 2012. *Thermal vals, switzerland*.

Ciancio, Daniela, and Christopher Beckett, eds. 2015. *Rammed Earth Construction: Cutting-Edge Research on Traditional and Modern Rammed Earth*. London, United Kingdom: Taylor & Francis Group.

Colorado River Water Users Association. Nevada. Las Vegas, Nevada, 3013 [cited October, 20 2014]. Available from http://www.crwua.org/colorado-river/member-states/nevada.

Decker, Bill. 2014. A proactive perspective: Raising a "sustainable water generation" to better care for water resources. *Water World.* September.

DesertSol. Public exhibit signage. in University of Nevada Las Vegas Solar Decathlon Team [database online]. Las Vegas, Nevada, 2013 [cited November, 14 2014]. Available from http://solardecathlon.unlv.edu/wp-content/uploads/2013/10/DesertSol-Public_Exhibit_Signage.pdf.

Dunn, Sarah, and Felsen, Martin. UrbanLab: Architecture + urban design. 2014 [cited October, 25 2014]. Available from http://www.urbanlab.com/h2o/.

EcoDrain. Take a smarter shower. 2014 [cited October 2014]. Available from http://discover.ecodrain.com/save-the-planet-save-money/?atrkid=V1ADWDA7E3157-17253695078-k-building%20energy%20efficiency-59053152638--d-m-none&gclid=CIezncnH1cECFdHm7AodOTgAfA.

"Energy Efficient Fiberglass Windows + Doors | Cascadia Windows." 2015. Accessed May 3. http://www.cascadiawindows.com/.

Eole Water. Clean technology for clean water. 2014 [cited October 2014]. Available from http://www.eolewater.com/gb/our-products/range.html.

Farias Leão, Rafael. 2014. *Washing-hands*. Porto Alegre, Rio Grande do Sul, BR: .

Friedman, Avi. 2013. *Innovative houses: Concepts for sustainable living*, ed. Gaynor Sermon. London: Laurence King Publishing Ltd.

Green, Andrew. 2005. *Comares tower and myrtle court, alhambra, spain*.

Hauser, Sigrid. 2007. *Peter Zumthor--Therme Vals*. Zürich: Scheidegger & Spiess.

Heins, Andrew. 2012. *Fish*. California: .

"High Efficiency Showerheads – Water Saving High Pressure Showerheads." Accessed May 2, 2015. http://www.amconservationgroup.com/categories/water-conservation-products/showerheads/?filter_gallons-per-minute=3064.

Holthaus, Eric. 2014. "Lake Mead Before and After the Epic Drought." *Slate*, July 25. http://www.slate.com/articles/technology/future_tense/2014/07/lake_mead_before_and_after_colorado_river_basin_losing_water_at_shocking.html.

Hubers, Marcel. 2004. *Alhambra; lions court*.

Hurtt, Steven. n.d. Thesis Meetings In Person.

Hutchins-Cabibi, Taryn, Bart Miller, and Anita Schwartz. 2006. *Water in the Urban Southwest: An Updated Analysis of Water Use in Albuquerque, Las Vegas Valley, and Tucson*. Boulder, Colorado: Western Resource Advocates. http://www.westernresourceadvocates.org/media/pdf/FINAL%203%20City.pdf.

International Living Future Institute. 2015. "Declare: The Ingredients Label for Building Products." Accessed May 2. http://declareproducts.com/.

Institute, Pacific. 2013. The world's water. Oakland, California: Pacific Institute, Vol 8, http://worldwater.org/wp-content/uploads/sites/22/2013/07/ww8-table2.pdf.

International, Belkin. Echo water. 2014 [cited October 2014]. Available from http://belkinbusiness.com/echo-water-0.

Joy, Rick. 2002. *Rick Joy: Desert Works*. New Voices in Architecture. Chicago : New York : Princeton Architectural Press: Graham Foundation for Advanced Studies in the Fine Arts.

Kats, Greg. 2010. *Greening Our Built World: Costs, Benefits, and Strategies*. District of Columbia: Island Press.

Kaufmann, Michelle, and Catherine Remick. 2009. *Prefab green*. 1st ed. Layton, Utah: Gibbs Smith.

Kenney, Douglas, and Robert Wilkinson. 2011. *The Water-Energy Nexus in the American West*. United Kingdom: Edward Elgar Publishing Limited.

Kuckro, Rod. 2014. "ELECTRICITY: Receding Lake Mead Poses Challenges to Hoover Dam's Power Output -- Monday, June 30, 2014 -- Www.eenews.net." *EnergyWire*. Accessed December 3. http://www.eenews.net/energywire/stories/1060002129.

Kuruvilla, Carol. 2013. "Brazilian Mechanic Creates Light Bulb Using Water, Bleach, and a Bottle." *New York Daily News*. August 14.

http://www.nydailynews.com/news/world/brazilian-mechanic-creates-light-bulb-water-bleach-bottle-article-1.1427011.

Livingston, Morna. 2002. *Waiting for rain*, ed. Clare Jacobson. New York, New York: Princeton Architectural Press.

McCown, Ken. 2014. *Southern Nevada Inventory of Sustainble Systems*. UNLV Downtown Design Center. Accessed November 25.

National Geographic. 2014. "Rain Shadow." *National Geographic Education*. Accessed December 5. http://education.nationalgeographic.com/education/encyclopedia/rain-shadow/.

National Renewable Energy Laboratory. n.d. "Home | BEopt." https://beopt.nrel.gov/.

"New Homes Las Vegas - KB Home." 2015. Accessed May 17. http://www.kbhome.com/new-homes-las-vegas.

New, Mitchell. 2011. "Tubac House." *TUBAC.house*. March 29. http://tubachouse.blogspot.com/2011/03/tubac-house.html.

Nordic Engineered Wood. 2015. "X-Lam | Cross Laminated Timber." Accessed May 2. http://www.nordicewp.com/products/x-lam/.

Nowak, Amelia. 2014. *Faucet*.

One Planet Communities. The prototype: BedZED. UK, [cited October 2014]. Available from http://www.oneplanetcommunities.org/communities/bedzed/.

Pham, Diane. Team las vegas' DesertSol home brings a base camp for desert exploration to the solar decathlon
. 2013 [cited October 2014]. Available from http://inhabitat.com/team-las-vegas-desertsol-home-brings-a-base-camp-for-desert-exploration-to-the-solar-decathlon/.

"Per Capita Energy Consumption" - Energy Realities - A Visual Guide to Global Energy Needs." 2014. Accessed November 25. http://www.energyrealities.org/chapter/meeting-our-needs/item/per-capita-energy-consumption/erp327B7C729A3B31D2B.

"Premier SIPs | Residential SIPs Framing Systems | SIP Homes." 2015. Accessed May 2. http://premiersips.com/residential-sips-framing-systems/.

"Pueblo." 2014. *National Tribal Healthy Homes*. Accessed December 13. http://tribalhealthyhomes.org/pueblo.htm.

Pittsburg Corning. 2015. “FOAMGLAS® Pittsburgh Corning.” Accessed May 2. http://us.foamglas.com/en/building/applications/.

Revnik, Yevgeny. 2014. *Bath*.

Sedlbauer, Klaus, Eberhard Schunck, Rainer Barthel, and Hartwig Kunzel. n.d. *Flat Roof Construction Manual: Materials Design Applications*. 1st ed. Institut fur Internationale Architektur-Dokumentation.

Skole, Jordan. 2014. *Dishwasher*. Detroit, Michigan: .

Sloan. New sloan AQUS® water reuse system model. 2010 [cited October 2014]. Available from http://www.sloanvalve.com/News_Press/Sloan_AQUS_Water_Reuse_System.aspx.

Southern Nevada Water Authority. 2014. “Las Vegas Wash Coordination Committee.” Accessed December 8. http://www.lvwash.org/html/index.html.

Southern Nevada Water Authority. Water sources. Nevada, United States, 2014 [cited November, 9 2014]. Available from http://www.snwa.com/ws/river.html.

Southern Nevada Water Authority. Water smart home. Las Vegas, Nevada, 2014 [cited October 2014]. Available from http://www.snwa.com/biz/programs_home.html.

Springs Preserve. The springs preserve. in Las Vegas Springs Preserve [database online]. Las Vegas, Nevada, 2014 [cited November, 19 2014]. Available from http://www.springspreserve.org/index.html.

Stachelski, Chris, Andy Gorelow, and Paul Skrbac. 2014. *The Climate of Las Vegas, Nevada*. National Weather Service Office.

“Stealth .8 GPF Toilet - Ultra High-Efficiency - Elongated UHET.” Accessed May 2, 2015.http://www.niagaracorp.com/water_conservation/products/toilets/detail?object=5274.

Sunseifer, Dimitry. 2013. *Power-plant*. Arkhangelsk, RU: .

Tabatabaie, Sara. 2012. *Las Aguas: A review of water shortage, water resource management and conservation programs in the las vegas valley*. Blogspot.

Thomas, Randall, and Trevor Garnham. 2007. *The elements of architecture: Environmental design in context*. New York, New York: Taylor & Francis.

Udelsman, Evan. 2014. *Leak*, http://thenounproject.com/term/leak/53019/ (accessed October 29, 2014).

United States Department of Agriculture, and National Water and Climate Center. 2014. "NRCS National Water and Climate Center - Climate Products - Climate Data - Wind Rose." Government. *Natural Resources Convervation Service*. Accessed December 5. http://www.wcc.nrcs.usda.gov/climate/windrose.html.

United States Department of Energy. 2014. "How Do Wind Turbines Work." *Energy.gov*. Accessed December 13. http://energy.gov/eere/wind/how-do-wind-turbines-work.

United States Department of Energy. Tankless of demand-type water heaters. District of Columbia, 2012 [cited November, 20 2014]. Available from http://energy.gov/energysaver/articles/tankless-or-demand-type-water-heaters.

United States Department of the Interior. 2014. "Taos Pueblo--American Latino Heritage: A Discover Our Shared Heritage Travel Itinerary." *National Park Service*. Accessed December 14. http://www.nps.gov/nr/travel/american_latino_heritage/Taos_Pueblo.html.

United States Environmental Protection Agency. Water use today. 2014 [cited October/23 October 27, 2014]. Available from http://www.epa.gov/WaterSense/our_water/water_use_today.html (accessed October 27, 2014).

United States Environmental Protection Agency. Tomorrow and beyond. District of Columbia, United States, 2014 [cited November, 10 2014]. Available from http://www.epa.gov/watersense/our_water/tomorrow_beyond.html.

United States Geological Survey. Total water use in the united states, 2005. in United States Geological Survey [database online]. 2014 [cited November, 8 2014]. Available from http://water.usgs.gov/edu/wateruse-total.html.

United States Green Building Council. Per capita water use. 2014 [cited October/27 2014]. Available from http://water.usgs.gov/edu/qa-home-percapita.html.

United States Green Building Council. 2014. "Solar Orientation." *LEED*. Accessed December 12. http://www.usgbc.org/credits/ea51.

University of Maryland. 2014. "WaterShed at the University of Maryland | U.S. Department of Energy Solar Decathlon 2011." *WaterShed At the University of Maryland*. Accessed October 7. http://2011.solarteam.org/about.

University of Nevada, Las Vegas. 2014. “DesertSol by Team Las Vegas | Solar Decathlon 2013 » Design Philosophy.” Academic. *DesertSol*. Accessed November 22. http://solardecathlon.unlv.edu/project/design-philosophy/#Energy.

“U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” 2014. Accessed November 23. http://www.eia.gov/state/?sid=NV#tabs-5.

Vincente. 2014. “Adobe.” *Efficient, Pure Solar Energy for All*. Accessed December 13. http://www.epsea.org/adobe.html.

Wagoner, Ainsley. 2013. *Toothbrush*. San Francisco, California:

Walton, Brett. 2010. The price of water: A comparison of water rates, usage in 30 U.S. cities. Circle of Blue.

“Water Supply Shortages | Water Scarcity | Climate Change.” 2014. Accessed December 4. http://www.global-warming-forecasts.com/water-supply-shortage-water-scarcity-climate.php.

Wujek, Joseph B. 2010. *Mechanical and Electrical Systems in Architecture, Engineering, and Construction*. 5th ed. Upper Saddle River, N.J: Prentice Hall.

Xeriscape Design, L. C. Before and after. Salt Lake City, Utah, 2013 [cited November, 15 2014]. Available from http://www.xeriscapedesign.com/project-gallery/before-after.

Yudelson, Jerry. 2010. *Dry Run: Preventing the Next Urban Water Crisis*. Vol. 1. Canada: New Society Publishers.

Zed Factory. Bedzed. London, UK, [cited October 2014]. Available from http://www.zedfactory.com/zed/?q=node/102.